VOL. 1

PNEUM

FOR

USE OF B

BY CHARLES

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PNEUMATICS;

FOR

THE USE OF BEGINNERS.

BY

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APPENDIX.

PNEUMATICS.

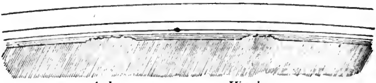
1. OUR knowledge of the atmosphere, as revealed to us by the united aid of Chemistry and Pneumatics, is one of the greatest triumphs of modern science. It was not until the close of the last century that air was removed from the list of ancient elements, and was proved to consist of two gases of essentially different chemical properties. Its physical properties were discovered earlier; but our present extensive knowledge of the atmosphere, considered chemically, physically, and meteorologically, is chiefly the fruit of modern investigation, the result of improved instrumental aid and methods of research. And it is natural to suppose that the working parts of so vast and complicated a machine as the atmosphere, which can be scarcely said to appeal to any one of our senses, should remain much longer unknown than the properties of solids and liquids, which are so much more obvious. Even the heavenly bodies, although appealing to only one of the senses, and removed from us by vast distances, are calculated by their beauty and the regularity of their motions, to attract attention, much more than an invisible attendant, which, although constantly present with us, performs most of its varied offices in silence and in secret.

2. The atmosphere, or sphere of gases (ατμοι), is the general name applied to the whole gaseous portion of this planet; as the term *ocean* is applied to its liquid, and *land* to its solid

portions. Being much lighter than either land or water, it necessarily floats or rests upon them; but, unlike the ocean, which is confined to the depressions of the solid surface, and covers only about three-fourths of it, the atmosphere is in sufficient quantity to cover the highest mountains, and to rise to nine or ten times their height above the sea-level, so as to form a layer over the whole surface, averaging probably between forty and fifty miles in thickness; which is about as thick in proportion to the globe as the liquid layer adhering to an orange after it has been dipped in water. The accompanying figure will convey an idea of the proportion which the highest mountains bear to the curvature of the earth and the thickness of the atmosphere. The concentric lines divide the atmosphere into six layers, containing equal quantities of air, showing the great compression of the lower layers by the weight of those above them.

Fig. 1.

Supposed height of the atmosphere:



3. The atmosphere consists essentially of two gases, called *oxygen* and *nitrogen*. In its pure state oxygen is remarkable for the energy with which it promotes combustion, respiration, and other chemical changes. An iron or steel wire, heated to redness at one extremity, and plunged into a vessel full of this gas, will take fire and burn brilliantly. If an animal be placed in pure oxygen, its pulses will throb with increased rapidity, and it will die from excess of vital action. The properties of nitrogen, on the contrary, appear to be of a negative character. It supports neither combustion nor respiration, and on the latter account it was formerly called

*azote.** It does not appear, however, to have any poisonous properties, like some other gases; an animal cannot live in it, simply from the absence of oxygen, not because nitrogen is in itself prejudicial: on the contrary, its uses in the atmosphere appear to be simply those of a dilutent; it subdues and modifies the activity of the oxygen, and for this purpose, exists in much greater abundance. Every atom or particle of oxygen is accompanied by four atoms or particles of nitrogen; that is, if any measure or volume of air be separated or decomposed into its component parts, the nitrogen will occupy four times as much space as the oxygen. It is, however, an important property of gases to mingle, or become *diffused*, together so intimately, that, although oxygen is somewhat heavier than nitrogen, these two gases always exist in the atmosphere in a state of mechanical mixtur, in the proportion of 1 to 4, and this without any regard to the localities from which samples of the air may be taken. In the crowded courts of our metropolis, as well as in the breezy downs of the country, in the arid deserts of Arabia, in the open ocean, in the polar regions, at heights accessible only to the balloon, in the fever hospital, and in the flower garden, the proportion of these two essential in gredtei of the atmosphere remains constantly the same.

And this fact will appear the more wonderful, when we consider the innumerable sources of vitiation tending to destroy the useful properties of the oxygen, by depriving it of its powers to support life and combustion. Indeed, these two very actions are the chief means of vitiating it, for during the combustion of our lamps, and candles, and fuel, and during the respiration of animals, a quantity of carbon is liberated, every six parts of which, by weight, unite with 16 parts by weight (or about 3,600 ti es their own bulk) of oxygen, to form a compound gs called *carbonic acid*, which resembles nitrogen, in not supporting animal life or combustion; but differs from it in being soluble in

* From α ζωη, privative of life.

water, having an acid reaction, and some other characteristic properties, which readily distinguish it from that inert element. Carbonic acid is always present in the atmosphere in small but varying quantities; and it is because the quantity is liable to change that this gas is not reckoned as one of the essential constituents of the atmosphere. In 10,000 volumes or measures of atmospheric air the mean proportion of carbonic acid is only five volumes; the proportion, however, is subject to constant variation, from 6·2 as a maximum to 3·7 as a minimum. Near the surface of the earth the proportion of carbonic acid is greater in summer than in winter, and during night than during day. It is also rather more abundant in elevated situations, as on the summits of high mountains, than in the plains; and although this gas is considerably heavier than its own bulk of pure atmospheric air (its specific gravity being about 1·52), yet it appears to be diffused through the whole mass.

When we consider that the innumerable animals which inhabit both the land and the water all depend more or less upon oxygen for their very existence; that combustion of various kinds, as carried on in our daily operations; that fermentation and other processes all *consume* immense quantities of oxygen, *i. e.* convert it into steam and carbonic acid, chiefly the latter, it does indeed appear wonderful that the quantity of carbonic acid in the atmosphere should be so small. By a beautiful arrangement, however, the carbonic acid thus formed is made to be the food of the vegetable world. The green parts of plants, under the influence of light, absorb carbonic acid, retain and assimilate the carbon, and restore the pure oxygen to the air. During the night, however, plants absorb oxygen and give out carbonic acid; but in the course of the twenty-four hours they give out considerably more oxygen than they consume, and in this way a compensation is made for the loss of oxygen occasioned by respiration and combustion.

The atmosphere also contains a variable quantity of

aqueous vapour, arising partly from combustion as above mentioned, but chiefly from contact with the surface of the sea, lakes, rivers, and moist soil. In 100 parts by weight of atmospheric air the mean quantity of watery vapour is nearly one part and a half. The amount, however, varies according to the temperature. At 50° (the mean temperature of England) the air can contain $\frac{1}{120}$th of its weight of water in an invisible state, without forming cloud, mist, or rain. It does not always contain so much, but the quantity cannot exceed this, without a portion being precipitated in a visible form. At a higher temperature, however, more vapour could remain invisible; thus at 82° (the mean temperature of the equator) the air may contain as much as $\frac{1}{43}$rd of its weight of invisible steam; and air that contained only $\frac{1}{120}$th would be injuriously *dry*, though the same air cooled down to 50° would be at its maximum of humidity.

There are other accidental ingredients in the atmosphere which are too numerous and in too small quantity to take account of. As the sea contains a little of everything that is soluble in water, so the atmosphere contains a little of everything capable of existing in the gaseous form at common temperatures. Ammonia, which is a compound of hydrogen and nitrogen, is present in the atmosphere, and is supposed to be the source of nitrogen in plants; while in crowded cities, and in the neighbourhood of gas-works, smelting-furnaces, sewers, stagnant pools, sulphur springs, &c., there is much local contamination of the air from the presence of different gases. Various forms of infection, malaria, and marsh-miasma probably arise from the presence of noxious gases in the air.*

4. This invisible compound fluid, the atmosphere, possesses many of the properties of solid matter, and also many that are peculiar to fluids. In a former treatise the chief properties by which solids are distinguished from fluids were

* The chemical history of the atmosphere is given more fully in the author's Rudimentary Treatise on Warming and Ventilation.

pointed out; but it is now necessary to consider these and other properties more fully with reference to the atmosphere.

In common with matter in every state, the air possesses *impenetrability*. It is obvious to the senses, as far as regards solids and liquids, that no two bodies can occupy the same place at the same time; in order that one body should occupy the place of another, it is obviously necessary that the second should move away or be displaced; but the evidence of the senses fails us in the case of air. If we step into a bath completely full of water, a portion will overflow precisely equal in bulk to that part of the body which is submerged; the same thing takes place in an *empty* bath as it is called, or a bath full of invisible air, and hence called empty. When a person enters a room, a quantity of air precisely equal to his own bulk is displaced, and escapes by the door, or window, or other opening. But the proof of the impenetrability of air may be made more obvious by the following experiment:—Plunge an inverted goblet into a vessel of water, keeping its edge horizontal, and it will be found that, to whatever depth we plunge the goblet, the water will not fill it entirely. The air will be *compressed* into a smaller space, but not annihilated or displaced. At a depth of 34 feet below the surface of the water, the vessel containing the air will be half filled with water; at 100 feet it will be three-quarters filled; at 1,000 feet it will be filled to within a thirtieth; but even this small remaining space contains *all* the air which previously filled the vessel, and in drawing it up again to the surface the air will expand to its original bulk and drive out all the water. In fact, we can only get rid of the air by *inclining* the vessel, when so much of the air as is below the level of the highest part of its mouth will rise in bubbles through the water and escape; and in this way all the air must be *decanted* or *poured up* before the vessel will be filled with water.

5. The *impenetrability* of air is alone sufficient to prove it

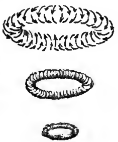
to be a material body, and, though formerly supposed to be without *weight*, it is now well known to possess this property in common with matter in all other known states; that is, it obeys the attractive influence of the earth and gravitates towards its centre. The proof that air has weight will be abundantly shown hereafter, when we come to speak of the barometer; but for our present purpose the following experiment will suffice:—A copper flask of the capacity of 100 cubic inches, furnished with a stop-cock, is fixed to one extremity of the arm of a balance, and accurately counterpoised by weights in the opposite scale. An exhausting syringe (an instrument to be described hereafter, 10) is then screwed upon the neck of the flask with the stop-cock open, and by working the syringe nearly the whole of the air can be pumped out of the flask. On closing the stop-cock, to prevent the admission of the air, and detaching the flask from the syringe, it is again weighed, and is found to have lost about 31 grains; or, in other words, 100 cubic inches of air weigh about 31 grains. On opening the stop-cock, the air will be heard to rush in, and the equilibrium of the balance will be restored as before.

If, instead of screwing the copper flask to an exhausting syringe we screw it to a *condensing* syringe, we can force or condense a quantity of air into the flask, in addition to what it naturally holds. After a few strokes of the condensing syringe the stop-cock of the flask is closed, to prevent the additional air from rushing out; the flask is then detached, and hung to the arm of the balance. The flask is no longer counterpoised, but will require additional weights in the opposite scale-pan to restore it to equilibrium. If we again apply the condensing syringe to the flask, it will be found that every additional stroke of the syringe will require additional weights in the scale-pan to restore equilibrium, on account of the additional quantities of air forced into the flask.

6. Here, then, is a very clear proof that air has weight,

and, in common with all heavy matter, air also possesses *inertia*, that is, it cannot be set in motion without the communication of some force ; and, when in motion, it cannot be retarded or brought to rest without the opposition of force. Its inertia (like that of all other bodies) is also exactly proportional to its *weight* ; and, as we have seen the latter to be very small compared with its bulk, a very small amount of force is sufficient to impart motion to a large bulk of air ; it obeys the laws of motion common to ponderable bodies, and its *momentum*, or amount of force which it is capable of exerting upon bodies opposed to it, is estimated in the same way as for solids, namely, by multiplying its weight by its velocity. The momentum of air may be illustrated by the following experiment :—Place three lighted tapers in a row at the distance of three inches apart ; then direct an unloaded gun towards the centre taper at the distance of ten feet, and set in motion the small volume of air contained in the barrel, by discharging the percussion cap on the nipple, the flame of the centre taper will be blown out, without in the least degree disturbing the other two. Another excellent illustration of the momentum of air, and the facility with which a rotatory movement may be communicated to it, is derived from the phenomena of smoke or steam which render the motions of the air visible. When bubbles of phosphuretted hydrogen burst in a still atmosphere, each one, as it bursts, produces a beautiful ring of smoke, expanding larger and larger as it ascends. The whole circumference of each circle is in a state of rapid rotation, as shown by the arrows in Fig. 2 ; it being this rotation, in fact, which confines the smoke within its narrow limits, and causes the circles to be so well defined. The same phenomena may often be observed in the first puff from the chimney of a

Fig. 2.



manufactory or of a steam-boat, and also from the mouth of a skilful tobacco-smoker. In the firing of ordnance on a still day, these rings may be seen on a grand scale, and still more perfectly if the mouth of the cannon be greased and no shot employed. In fact, any force acting suddenly upon the air from a centre imparts to it a rotatory motion.

The momentum of air is usefully employed as a mechanical force in imparting motion to windmills and ships; but it occasionally exerts itself with fearful effect in those strong winds or hurricanes which sometimes occur in the West India islands, where trees are torn up by the roots, buildings levelled to the ground, and where the sea is driven with irresistible fury over the desolated country. Such awful calamities are caused by the momentum of the air being greater than the force by which a tree clasps the earth or a building its foundation.

7. Another consequence of the weight of air is its *pressure.* We have already seen that 100 cubic inches of air weigh about 31 grains. It is necessary, however, in order to obtain this result, that the experiment be performed at the level of the sea: it is further necessary that at the time of the experiment the barometer should stand at 30 inches and the thermometer at 60°. But, disregarding for the present these two last conditions, let us note the change arising from difference of level only. At the level of the sea the 100 cubic inches of air contained in the flask would weigh say 31 grains. On taking this flask to the top of a mountain 20,000 feet high, the 100 cubic inches will have expanded to 200: so that, if the flask be made of some elastic material, it will have expanded to twice its former size; or, if the copper flask full of air have its stop-cock closed at the level of the sea, and opened at an elevation of 20,000 feet, exactly 100 cubic inches of air will rush out, leaving 100 cubic inches of air behind, of half its former density. The reason for this is, that at the height of nearly $3\frac{1}{2}$ miles we have more than half the atmosphere below us, and

the air of the flask has to bear only half the superincumbent pressure that it bore at the sea-level. Now it is a curious law, peculiar to gaseous matter, that its density is commonly proportional to the pressure that confines it, that is to say, by doubling this pressure we compress air into half its former bulk (as in the instance of a diving-bell under 34 feet of water); and on the other hand, on removing half the ordinary pressure from air, it expands to twice its ordinary bulk; so that there appears no limit to the space which any quantity, however small, would fill, if relieved of all pressure. We shall return to this important law presently; but meanwhile it must not be supposed, because an elevation of 3½ miles leaves one-half of the atmosphere below us, that we should reach the limits of its existence at double that height, or 7 miles. At that height (supposing it attainable) we should still have one-fourth of the atmosphere above us, and 100 cubic inches of air from the sea-level would expand into 400, because the upper parts of the atmosphere, having less weight to bear than the lower parts, expand into far greater bulk; so that not under an elevation of 45 miles is the atmosphere supposed to be limited by the coast-line of eternal space.

Thus the aërial ocean is not, like the sea, of nearly the same density throughout its depth, but gets thinner and thinner from the bottom upwards, so much so that the first 3½ miles above the earth's surface contain as much air as all the remaining 41 or 42 miles.* The cause for this is, that the air at the level of the sea has to bear the weight of the whole mass of atmosphere above it, which of course acts as a powerful mechanical force in increasing the density, and consequently the pressure of the lower strata.

The pressure of the atmosphere at the sea-level can be estimated by a simple contrivance. Two hollow hemispheres of brass, Fig. 3, fitting together with smooth edges, are placed in contact; the lower hemisphere is furnished with a

* See the diagram, Fig. 29 (57).

short tube opening into it, and this tube can be opened or closed at pleasure by means of a stop-cock. On screwing the tube into an exhausting syringe, and placing the two hemispheres together, the air can be withdrawn from the hollow sphere thus formed, and on turning the stop-cock, before removing the apparatus from the syringe, the air is prevented from entering. A handle may now be screwed to the short tube, and if two persons pull in opposite directions, they will be unable to separate the hemispheres. On turning the stop-cock, however, the air rushes in, and the hemispheres fall asunder by their own weight.

Fig. 3.

Now the force which binds these two hemispheres together is the pressure of the atmosphere, which may easily be calculated by suspending them, when exhausted, by the upper handle, and adding weights to the lower handle. Suppose the sphere to be 6 inches in diameter, its section through the centre will be about 29 square inches; and, supposing the vacuum to be perfect, a weight of 420 lbs. will be required to separate the hemispheres. Now $\frac{420}{29}$ = about $14\frac{1}{2}$ lbs., the amount of atmospheric pressure upon one square inch of surface.*

There are many other methods of proving the important fact, that the weight or pressure of the air is equal to between 14 and 15 lbs. on every square inch of surface at the level of the sea; or, in other words, a column of atmospheric air one inch square, resting on any surface at the sea-level,

* These hemispheres are called the *Magdeburg hemispheres*, and the experiment the *Magdeburg experiment*, from the place where Otto Güricke, one of the inventors of the air-pump, resided. In 1654 he had the honour of exhibiting the Magdeburg experiment on a large scale, before the princes of the empire and the foreign ministers assembled at the diet of Ratisbon. The force of two teams, consisting of a dozen horses, pulling in opposite directions, was found insufficient to separate the hemispheres.

and extending to the top of the atmosphere, weighs between 14 and 15 lbs. This will be more clearly seen when we come to speak of the barometer; but we may here anticipate the surprise of the reader who approaches this subject for the first time. He may regard such results as these as scientific curiosities, in which he is in no way concerned; but a moment's reflection will convince him that the same force which held the hollow hemispheres together, is present and active, as well for animals as for inorganic matter. If it can be proved that a column of air one inch square and about 45 miles high weighs about 15 lbs., it is evident that this pressure must be as true for a square yard, or a square mile of surface, as for a square inch; the only difference is in extent; for, if we wish to know the pressure on a square yard, or mile, we must calculate the number of square inches in such a surface, and multiply this number by 15, and the product will give the atmospheric pressure in pounds on the larger surface. But since we have seen that air is impenetrable, and that our bodies displace it, it must be evident that this pressure is also exerted on every part of the surface of our bodies, as well as of the earth on which the air rests; for the pressure of a *fluid* on any surface immersed in it is exactly equal, whether the surface be horizontal, vertical, overhanging, or even facing downwards like a ceiling.* We dwell on the floor of an ocean of air 45 miles deep, and are as much subject to its pressure, as the bodies of fishes, which inhabit the floor of the liquid ocean, are to the column of water above them. In order, therefore, to calculate the amount of atmospheric pressure on our bodies, we must ascertain the number of square inches on their surface, and multiply this number by $14\frac{1}{2}$. In this way it will be found, that the atmospheric pressure upon the body of a man of ordinary stature amounts to no less than 33,600 lbs., or

* The demonstration of the proposition, that fluidity consists in the transmission of pressure in all directions, is given in Rudimentary Mechanics, Part III.

about 15 tons! Why, then, it may be asked, is he not crushed to death, instead of being entirely insensible of this enormous pressure? A few examples will explain this. There are many delicate and fragile animals which live at great depths in the sea, often from 2,000 to 3,000 feet below its surface. These creatures, therefore, have to sustain the pressure of a column of water of that height, a pressure of from 60 to 90 times greater than that of the atmosphere upon our bodies. Yet these animals are not crushed; they move about with perfect ease, under circumstances still more surprising than those under which we live. And the reason is, that this hydrostatic pressure is equal on all sides; the bodies of these animals are equally pressed above, below, and around, and the fluids within the animal are also either of similar density, or they are nearly incompressible, so that all these different pressures counterbalance each other. In the same manner the fluid atmosphere presses equally in all directions, and the human body immersed in it may be compared to a sponge plunged into deep water; it is not crushed, because the water fills the cavities of the sponge, and also surrounds it entirely. In like manner our bodies, and even our bones, are filled either with liquids capable of sustaining pressure, or with air of the same density as the external air, so that the outward is counteracted by the inward pressure. Now let us see what are the consequences of removing this pressure. Some fishes, which live at great depths in the sea, are provided with swimming-bladders, or little bags full of air. On raising them to the surface, the water-pressure is removed, and the bladder expands to such a degree as to kill the creatures instantly. In like manner, if we were raised towards the surface of our aërial ocean, our bodies would swell, and probably burst. We become painfully sensible of a partial effect of this kind, by removing the external pressure from a portion of the skin, as in the operation of cupping. The cupper drives out the greater portion of the air from the cupping-glass, by holding it over the flame of a

spirit-lamp, and then suddenly claps the glass on the skin, which has been previously cut by a number of small lancets. The cup adheres by the pressure of the air on the outside, while the flesh beneath the glass, being relieved from pressure, expands, and forms a projection within the cup. The blood-vessels beneath the incised portion of the skin, being also relieved from pressure, discharge their contents into the rarefied space formed in the cup.

The pressure of the atmosphere may be illustrated by the following simple experiment :—Fill a glass of water to the brim; cover it with a piece of paper; press the paper to the edge of the glass with the flat surface of the left hand, while with the right hand the glass is to be suddenly inverted. The left hand can then be removed, and, provided the paper be kept in a horizontal position, the water will be supported in the glass by the pressure of the air against the paper. A glass phial, with a narrow neck, may be filled with water and inverted, and the water will not escape, because its adhesion to the sides of the neck, and the pressure of the atmosphere, sustain the liquid column. If this adhesion be overcome by shaking the bottle, or inclining it on one side, bubbles of air will pass up on one side, while equal quantities of water escape on the other. In beer-casks, &c., a vent-hole is provided at the top, to allow the air to enter in proportion as the liquid is drawn off below.* In the wine districts of France an ingenious little instrument, entitled a *tâte-vin*, or wine-taster, Fig. 4, is used for taking out a small portion of wine from a cask. It consists of a tube of tinned iron, of which the transverse dimensions increase gradually from the top to near the bottom, which terminates in an inverted cone, the point of which is open: there is also a small circular opening at the top. Now, on holding this tube

* In those cases where the beer escapes freely without opening the vent-peg, a quantity of carbonic acid has accumulated at the top of the liquid, and being under pressure, its elastic spring acts upon the liquid, and forces it out when the tap is opened.

Fig. 4.

by the handle, and passing it into a cask of wine, through the bunghole, wine will enter by the lower hole, until it attains the same level in the tube as in the cask, and in doing so it will drive the air out through the hole at the top. On taking the tube out of the cask, the wine will flow back again from the lower hole, and the air will re-enter by the top hole; but if the thumb be placed over the top hole, the air cannot re-enter, and consequently the wine cannot escape from the point at the bottom. The moment the thumb is removed, the wine begins to flow, and in this way a small wine-glass may be filled without wasting a single drop. The little glass instrument called a *pipette*, so useful in the laboratory, acts on the same principle.

8. We have thus far illustrated certain properties which air enjoys in common with solids, namely, *impenetrability*, *weight*, *inertia*, *momentum*, and *fluid pressure in all directions*. We have also slightly noticed its *compressibility*, and its *elasticity* when compressed. This last property requires a more extended notice, for, although common to all matter, it is so much more obvious in airs and gases as to be sometimes regarded as their distinguishing feature, and to gain for them the somewhat ambiguous title of *elastic fluids*.

Airs and gases are so different in structure from solids and liquids, that it seems difficult to suppose them to be regulated by the same mechanical laws. The atoms or particles of solids are held together by an attractive force called *cohesion*, which differs in different solids, as is evident from the various degrees of force required to crush or grind them to powder. In liquids the attraction of cohesion is so weak, that the particles glide over each other with the greatest ease, and instantly mould themselves to the form of the vessel in which they may be contained. Thus they would appear to have *no* cohesive force; but that they have *some*

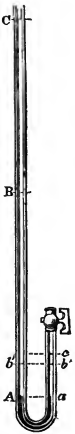
is evident by the coherence of every *drop* of water. In airs, gases, and vapours, however, this cohesive attraction is altogether absent. The gaseous particles not only have no cohesive attraction, but, on the contrary, a powerful *repulsion*, whereby they are constantly endeavouring to separate themselves as far as possible from each other. It is this repulsive force which constitutes the elasticity of aëriform bodies, of which we have now to speak.

A thin fragile vessel of any size is not crushed by the pressure of the atmosphère, on account of its perfect equability, the external pressure being exactly counterbalanced by the internal. We have only to remove one of these pressures, and we shall witness the energy with which either of these forces acts when unrestrained by the other. If the neck of a square glass vessel be screwed into an exhausting syringe, and the internal air removed, it will be crushed into small fragments by the external atmospheric pressure. So, on the contrary, if a similar vessel be carefully closed at the neck and placed under the receiver of an air-pump, on removing the external pressure the vessel will be blown to pieces by the pressure or elastic force of the air inclosed within the vessel.

We see, from this last experiment, that a portion of air cut off from all communication with the atmosphere still exerts a pressure in all directions against the sides of the vessel containing it, and it can be proved that this internal pressure is exactly equal to the pressure which an equal surface undergoes from the weight of the external atmosphere. But this internal pressure cannot arise from the weight of the included air (for this is only a few grains); it must therefore arise from its elasticity, or expansive force; that is to say, the force with which it tends to expand to its natural bulk, or that bulk which it would occupy if subject to no pressure; if, for example, it were removed to the top of the atmosphere.

9. The elasticity of air and the law by which it is regu-

Fig. 5.



lated, can be very well illustrated by means of a long bent glass tube, Fig. 5, open at its longer extremity, and furnished with a stop-cock at the shorter. The stop-cock being open, a quantity of mercury is poured into the open end. The surfaces of the mercury A *a* will of course stand at the same level in both legs. The two columns of air, A C and *a* D, sustain a pressure equal to the weight of a column of air continued from A and *a* to the top of the atmosphere. If we now close the stop-cock D, the effect of the weight of the whole atmosphere above that point is cut off, so that the surface *a* can sustain no pressure arising from the weight of the atmosphere. Still the level of the mercury remains the same, because the elasticity of the column of air *a* D is precisely equal to the weight of the whole column before this small length was cut off. The surface A is still pressed by the whole atmospheric column, and thus we see that these two different properties of the atmosphere, its *elasticity* and its *weight*, exactly counterbalance each other.

Now we know that the atmospheric pressure under ordinary circumstances is equal to 14½ lbs. on the square inch, or to a column of mercury 30 inches high. It is evident, therefore, that the atmospheric pressure acting on A is the same as would be produced by a column of mercury 30 inches high resting on the surface A. So also, the force with which the air confined in *a* D presses by its elasticity on the surface *a* is also equal to a column of mercury 30 inches high. The pressure of the atmosphere acting on the surface A is transmitted by the mercury to the surface *a*, and balances the elastic force of the isolated column *a* D.

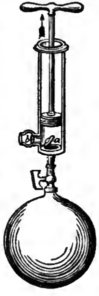
If we now pour an additional quantity of mercury into the open end of the tube at C, an increased pressure, arising from the weight of the metal, will be transmitted to the surface *a*, and will prevail over the elasticity of the confined air; the surface *a* will therefore rise towards D, compressing the air into smaller space. On continuing to pour in mercury until the surface *a* rise to *b*, or half-way between *a* and D, that is, until the confined air is compressed into exactly half its former limits, it will be found, on drawing a horizontal line from the surface *b* to the opposite point *b′* in the longer limb, that the column of mercury *b′* B measures exactly 30 inches, the weight of which is equal to the atmospheric pressure. The force with which the surface *b* is pressed upwards towards D is, therefore, equal to *two atmospheres*, or double the force with which *a* was pressed upwards towards D. Hence it appears that the elasticity of the confined column of air *b* D, is double its former elasticity when filling the space *a* D, so that when the air is compressed into half its volume its elasticity is doubled. If we again pour mercury into the tube at C, until the air inclosed in the shorter limb be reduced to a third of its bulk, as at *c* D, the compressing force will be equal to three times the atmospheric pressure. The height of the compressing column of mercury would reach to C, namely 60 inches above the level *c*. If we still add mercury until the column rise to the height of 90 inches above its level in the short limb, the elastic force of the confined air would be four times greater than at first, and it would be compressed to the bulk of one-fourth of its original volume.

It appears, then, that *the elastic force of air varies in exactly the same proportion as its density;* and this simple and important law, which is called, after its discoverer, the *law of Mariotte*, applies not only to air, but to all gaseous bodies when subject to such variations of pressure as can be readily commanded. Air has been allowed to expand into more than 2,000 times its usual bulk, and it would have

expanded still more if a greater space had been allowed. Air has also been compressed into less than a thousandth of its usual bulk, so as to become denser than water; but its elasticity has not been exactly determined at these extreme degrees, either of condensation or rarefaction; so that we have no proof that the law of Mariotte applies so extensively. On the contrary, recent experiments on the compression of gases render it nearly certain that they all vary from this law when subject to very great pressure, their density being increased in a greater ratio than their elasticity; this variation, however, is less in air than in most other gaseous bodies, and the simple law is found to apply to it very accurately when condensed as much as 50 times, and also when allowed to expand to several times its usual bulk.

10. The principle of those useful instruments, the exhausting syringe and the air-pump, depends upon the elasticity of the air. The exhausting syringe, Fig. 6, consists of a cylinder of brass or some other metal, with a piston or plug accurately fitting it. The lower part of the cylinder contains two valves or little doors, the one opening upwards into the cylinder, and the other at the side, out into the air. The vessel to be exhausted is screwed into a short tube projecting from the cylinder. This vessel must be furnished with a stop-cock, to prevent the air from re-entering after the exhaustion is complete. Now, suppose the vessel to be screwed into the short tube, its stop-cock open, and the piston at the bottom of the cylinder. Supposing we drew up the piston *instantaneously*, or in *no time*, a *vacuum* or empty space must evidently be left between the bottom of the cylinder and the piston. Consequently the air in the vessel, being no

Fig. 6.



longer counterbalanced by the atmospheric pressure, expands by its elasticity, forces open the valve *a*, and fills the empty space below the piston. When the piston is drawn progressively to the top of the cylinder, no vacuum is formed, the air from the vessel expanding and following it all the way. After this the piston is forcibly driven down again, whereby the valve *a* is closed, and *b* is opened; the whole of the air in the cylinder is thus driven out through *b*, and when the piston is at the bottom of the cylinder matters are in the same state as at the commencement of the operation, except that the air in the vessel is much less dense and elastic than before. On drawing up the piston a second time, the external air cannot enter through *b*, because this valve opens outwards, and the atmospheric pressure upon it from without only serves to close it more securely. The valve *a*, however, is immediately forced open a second time by the remaining air in the vessel, which again fills the empty space that would otherwise be left by the drawing up of the piston a second time. The piston is again depressed, the valve *a* is again closed, and the air in the cylinder again forced out through *b;* and in this way the action is carried on until the air in the vessel has too little elasticity to open the valve *a*. The *exhaustion* is then said to be complete.

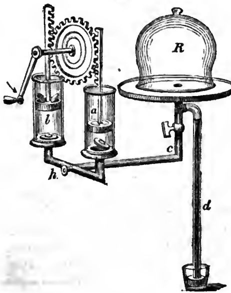
Now it is evident that a perfect vacuum, or empty space, cannot be formed in the vessel by this contrivance. A small portion of air must always be left in the vessel. If the cylinder be of the same capacity as the vessel, and the weight and friction of the valve be regarded as nothing, one-half of the air will pass out of the vessel by the first stroke of the piston; that is, on raising the piston to the top of the cylinder, and then depressing it again to the bottom, the vessel will be deprived of exactly half of its contents; the remaining half will still completely fill the vessel, but its atoms or particles will be farther apart, its density will be diminished one-half, and, consequently, its elasticity will be diminished in the same proportion. The second stroke of the piston

will again diminish the air in the vessel by one-half; that is, the air left after the second stroke will be one-fourth of its former density and elasticity. We may carry out these results to greater length, by collecting them in a tabular form. The quantity of air in the vessel before the first stroke is to be regarded as unity.

Stroke.	Goes out.		Left in vessel.	Elastic force of the remainder.		
1st,	one-half of 1	=	$\frac{1}{2}$	15 inches of mercury, or	7·35	lbs. per sq. in
2nd,	one-half of $\frac{1}{2}$	=	$\frac{1}{4}$	$7\frac{1}{2}$ inches of mercury, or	3·675	do.
3rd,	one-half of $\frac{1}{4}$	=	$\frac{1}{8}$	$3\frac{3}{4}$ inches of mercury, or	1·837	do.
4th,	one-half of $\frac{1}{8}$	=	$\frac{1}{16}$	1·875 ins. of mercury, or	·918	do.
5th,	one-half of $\frac{1}{16}$	=	$\frac{1}{32}$	0·9375 in. of mercury, or	·459	do.
6th,	one-half of $\frac{1}{32}$	=	$\frac{1}{64}$	0·4687 in. of mercury, or	·229	do.
7th,	one-half of $\frac{1}{64}$	=	$\frac{1}{128}$	0·2344 in. of mercury, or	·114	do.
8th,	one-half of $\frac{1}{128}$	=	$\frac{1}{256}$	0·1172 in. of mercury, or	·057	do.
9th,	one-half of $\frac{1}{256}$	=	$\frac{1}{512}$	0·0586 in. of mercury, or	·028	do.

Thus, after the ninth stroke, the remaining air will only be $\frac{1}{512}$th of its original quantity; and, as it still occupies the same space, it has only $\frac{1}{512}$th the density and elastic force, which is equal to a pressure of only 0·028 lbs. to the square inch, which would scarcely be sufficient to raise the valve.

Fig. 7



11. The air-pump, Fig. 7, is nothing more than a duplication of the exhausting

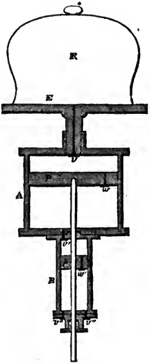
syringe, with this difference, that the valve through which air is forced out of the cylinder, is not placed as at *b*, Fig. 6, but in the piston or plug itself. Two of these syringes, *a b*, or *barrels*, as they are called, are arranged side by side, and the motion given to their pistons is so managed (in experimental machines by a toothed wheel and racked piston-rods) that, while one piston is ascending and drawing out the air, the other is descending and expelling the air already drawn out of the vessel to be exhausted. Each barrel is furnished with a valve at the bottom, opening upwards, so that, during the ascent of either piston, the air below the valve forces it open and fills the barrel. During the descent of either piston this valve is of course closed, and another valve, situated in the piston itself, and opening upwards, allows the escape of the air between the bottom of the barrel and the piston. In pneumatic experiments the vessel to be exhausted, R, is called a *receiver;* it is made of stout glass, its edge is ground flat, and smeared over with pomatum before it is placed on the metal plate *t*, called the *table* of the air-pump. By this means the receiver is brought into air-tight contact with the table, and forms a transparent chamber, in which any substance or arrangement of apparatus previously placed, may be observed under any amount of rarefaction that may be given to the inclosed air. The table is perforated at its centre with a hole, which communicates by a bent metal tube *c*, with the barrels *a b*. This tube is furnished with a stop-cock, which, being closed, prevents any leakage of air into the receiver from the barrels, and, when open, allows them to act upon the inclosed air. The air is readmitted into the receiver by a perforation into the bent metal tube at *h*. This hole is closed by a thumb-screw, made air-tight by a washer of leather. One extremity of a bent glass tube *d* opens into the metal tube *c*, while the other extremity dips into a cistern of mercury. This tube, which is more than 30 inches in length, acts as a gauge, and indicates, by the ascent of the mercury within it, the amount of rarefac-

tion in the receiver; because, as the rarefaction proceeds in the receiver, the elastic force of the air pressing upon the mercury in the gauge-tube is diminished. Indeed, with the first stroke of the pump, it immediately becomes less than the pressure of the external atmosphere on the surface of the mercury in the cistern: consequently, this external pressure prevails, and forces mercury up to a certain height in the gauge-tube. As the rarefaction of the air in the receiver proceeds, its elastic force is diminished, the atmospheric pressure acts with increased effect, and the mercury rises higher and higher in the tube. The weight of the column of mercury thus raised, combined with the elastic pressure of the air remaining in the receiver, is equal to the atmospheric pressure, and it is evident that the elastic force of the air in the receiver must be equal to the excess of the atmospheric pressure above the weight of the column of mercury in the tube. If a common barometer hanging up in the room stand at 30 inches, and the mercury in the gauge at 20 inches, the pressure of the air in the receiver is equal to 10 inches of mercury, or one-third of that of the external atmosphere. The density of the air in the receiver is also one-third of that of the external air, showing that two-thirds of the air have been removed.

12. In the foregoing description of the air-pump we have omitted details, which, although they make it a more efficient instrument in the hands of the man of science, do not affect its principle. In the best air-pumps the valves at the bottom of the barrels are not opened by the elastic force of the air in the receiver, but by a mechanical contrivance working in the piston-rods. In the French air-pumps exhibited in the Great Exhibition the barrels were of glass, so that the working of the valves could be shown, and their condition at all times be ascertained at a glance. In Newman's air-pump the table was formed of a stout slab of glass, instead of metal as heretofore. In Siemin's air-pump (Fig. 8) the two cylinders or barrels differ in size and arrangement.

The smaller barrel is applied either to the bottom or top of the larger, while the valved pistons belonging to each are attached to one and the same piston-rod. The air withdrawn from the receiver is condensed in the lower cylinder to one-fourth part of its original volume, and thus has sufficient elasticity to pass through the discharging-valve and escape, the opposing pressure of the atmosphere on that valve being thus counteracted from within. In Fig. 8, A is the exhausting cylinder, B the second cylinder, equal in length to the first, and fixed to its lower part, but having only one-third or one-fourth of its sectional area, and consequently one-third or one-fourth of its cubical contents. The cylinders are separated by a plate forming at once the bottom of the upper and the top of the lower cylinder, the only air-passage between them being a silk valve v'. In each cylinder works a valved piston, P and p, attached to a piston-rod common to both, and passing through a stuffing-box in the plate. The distance between the pistons is such, that when P is in contact with the top of the upper or exhausting cylinder A, p is in contact with the top of the smaller or lower cylinder; and when P is in contact with the bottom of the large cylinder, p is in contact with that of the small cylinder. The table, or pump-plate E, placed above the large cylinder A, supports the receiver R, or other vessel to be exhausted, from which the air flows through the valve v, during the descent of the piston. The motion of the pistons is effected by means of a

Fig. 8.



short crank with a jointed connecting-rod, converting the circular motion given by the lever handle into a vertical one, which is maintained by means of a cross-head, with rollers working between guides. The action of the pump is as follows:—The descent of the piston P tends to produce a vacuum in the exhausting cylinder A, by causing a difference of pressure above and below the first valve *v*, in the top of A, so that the elasticity of the air in the receiver causes it to pass through the valve *v*. At the same time the air below P is pressed through the valve *v'*, in the plate which separates the cylinders, and enters B, in which a vacancy is simultaneously made for it by the descent of the piston *p;* and in consequence of the difference of capacity of the two cylinders, it becomes reduced to one-fourth of its original bulk, its elasticity being proportionally increased. The air contained in the small cylinder below the piston *p*, will in like manner be pressed through the valves *v''*, *v'''*, into the external atmosphere. During the ascent of the pistons, the valves *v'*, *v''*, *v'''*, will be closed, and *v w* opened by the upward pressure of the air in the cylinders, and also by the atmosphere, thus allowing the air in each cylinder to pass through the pistons as they rise, in order that in the following downward movement the air, which during the previous stroke of the pump issued from the receiver into the exhausting cylinder, may be withdrawn from that into the lower cylinder, while the air condensed in the latter may be finally expelled into the atmosphere.

Mr. Siemins states that the ordinary air-pump cannot be made to remove more than $\frac{99}{100}$ of the air from the receiver. "Let us suppose," he says, "that in the new air-pump the piston P leaves $\frac{1}{100}$ of the air in the exhausting cylinder A, undisplaced, and that the piston *p* cannot be brought within $\frac{1}{100}$th part of the length of stroke of the top or bottom of the smaller cylinder, the working having been continued until no further exhaustion is effected. At this period the piston *p* will leave in the cylinder B during the downward

stroke $\frac{1}{100}$ of its bulk of air of the atmospheric density unexhausted; if it be raised again, this portion of air will expand and fill the cylinder B with air, the density of which will be only $\frac{1}{100}$ that of the atmosphere. The piston P will, at the same time, ascend to the top of the exhausting cylinder A, filled with air of the same density as that remaining in the receiver; but the exhaustion having reached its utmost limit, during the next downward stroke no air will be discharged from cylinder A into cylinder B; the air above the piston in the latter will, at the termination of this stroke, have expanded 100 times, and having previously expanded to an equal amount during the upward stroke, it will now be reduced to the density $\frac{1}{10000}$ that of the atmosphere. If no force were required to open the valve v', air would, in this state of things, pass from the upper into the lower cylinder, unless that in the former, a hundred times compressed as it would be at the end of the downward stroke, were not still rarefied 10,000 times; or what is the same thing, if it were not, when it filled the cylinder A, one million times rarefied. We find, therefore, that by the addition of the second cylinder, the vacuum may be rendered 10,000 times more perfect than if the cylinder A had been employed alone in the manner of an ordinary air-pump."*

13. From the air-pump we pass to the common *household* or *suction* pump, as it is sometimes called. The term *suction* is still applied to several operations and instruments of the pump kind. This term is an unfortunate one, and requires to be explained away. When we place one end of a straw in the mouth, and the other end in water, and are said to *suck up* the liquid, we do no such thing. We merely draw into the mouth the portion of air confined in the tube, and then the pressure of the air which is exerted on the surface of the liquid, being no longer balanced by the elasticity of

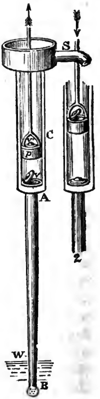
* "Description of an Improved Air-pump, applicable to Philosophical and Manufacturing Purposes, invented and patented by C. W. Siemins." Messrs. Knight, of Foster-lane, Cheapside, London, manufacture these pumps, and sell them at £21 each. The exhausting cylinder is 3 inches in diameter.

the air in the tube, forces the liquid up into the mouth. If the straw were gradually increased in length, without increasing its whole capacity, we should find a certain length at which (however small the tube) we should not be able to raise the water into the mouth; for it would not rise more than a certain number of feet above its former level; and no sucking, even by the most powerful machinery instead of the mouth, could ever raise it more than 34 feet above that level, because the atmospheric pressure cannot counterbalance a column of water of a greater height than between 33 and 34 feet. And if we try to suck up mercury through a long tube, we shall be unable to raise it more than a few inches by the mouth, nor by the best air-pump more than about 30 inches (viz. the height at which the mercury of the barometer stands at the time), because the atmosphere cannot balance a column higher than this. Our reputed powers of suction, therefore, have nothing to do with the fluid to be raised; for that work is done by the atmospheric pressure only: we assist it or bring it into play by using the mouth as an air-pump in withdrawing the air from the tube by enlarging the cavity of the mouth or lungs. In a boy's squirt, Fig. 9, the same principle is in operation. This simple but ingenious little instrument consists of a metal cylinder drawn at one end into a point, and furnished with a plug or piston. On introducing the point into water and drawing up the plug, a vacuum would be formed below it, did not the water rise and fill it by atmospheric pressure.

Fig. 9.

14. A similar but somewhat more complicated process is carried on in the common household pump. A long pipe A B, Fig. 10, dips at one end into the water of a well W, the other end is furnished with a valve *e*. Above this pipe is another and wider pipe C, called the *barrel*, containing a plug or piston *p*, furnished with a valve *v'*, in the centre; both these valves open upwards. The piston is worked up and down by means of a lever called a *brake*. There are, however, various ways of working the piston, which of course

Fig. 10.



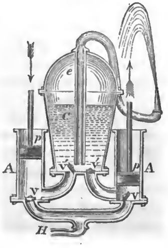
do not affect the principle of the pump. At the commencement of the operation of pumping, the water in the well and in the pipe A B stands at the same level. On raising the piston, a vacuum would be formed below it; but the air in A B by its elasticity raises the valve *v* and fills the barrel. This increased expansion of the air in A B diminishes its elasticity, so that water is forced up into A B to a certain height by the atmospheric pressure on the exposed surface of the water in the well. On depressing the piston, the valve *v* is closed and the valve *v′* forced open (as in Fig. 10, 2), through which the air between *v* and the bottom of the piston escapes. On raising the piston a second time, more air rushes from A B, and the column of water in the pipe rises higher. In this way by alternately raising and depressing the piston, all the air is drawn out of the pipe, and the column of water rises up to the valve *v*. On again raising the piston, water instead of air now opens the valve *v*, and rushes into the barrel, and, on lowering the piston, the water closes this valve *v*, thereby preventing it from again flowing back into the well. At the same time the water forces open the valve *v′*, and streams through it, so that water is now both above and below the piston. On continuing the action, the water rises higher and higher above the piston, until it reaches the spout S, where it is discharged.

Now it is quite evident that the length of the pipe A B must have a limit; since the atmosphere by its pressure is capable of supporting a column of mercury 30 inches high, and as the specific gravity of water is about 13½ times less

than that of mercury, it follows that a force which can sustain 30 inches of the heavier fluid will sustain a column of the lighter fluid $13\frac{1}{2}$ times greater in height, or about 405 inches, or 34 feet, instead of 30 inches. But as the barometric column in this country oscillates between 28 and 31 inches in height, it follows that a column of water supported by the atmosphere must also be subject to a proportional variation. Besides, as the mechanism of a common pump is by no means exact, some allowance must be made for its imperfections. Hence the length of the pipe A B ought never to exceed 30 feet above the level of the water in the well. It was the lucky accident of erecting a pump over a deep well at Florence that led to the discovery of the barometer and the pressure of the atmosphere, as already narrated in a companion treatise.*

15. When it is desired to raise water to a great height, advantage is taken of the elasticity of a confined portion of air condensed into a smaller space than it usually occupies under atmospheric pressure. Such is *the fire-engine*, the principle of which will be understood from the section shown in Fig. 11. H is the pipe, or hose, which is prolonged to the plug, or water-pipe, whence the supply of water is obtained. This pipe H communicates with two valves V V, which open into the pump-barrels of two forcing-pumps A A,† containing solid pistons *p p*. The piston-rods of these are

Fig. 11.



* See Introduction to the Study of Natural Philosophy; new edition (11).

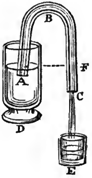
† *I. e.*, pumps like the *exhausting syringe*, first described (10), instead of the air-pump (11) and common water-pump just mentioned.

connected with a working beam so arranged as to be worked by a number of persons on each side. From the sides of the pump-barrels above the valves V V proceed force-pipes which communicate with an air-chamber C by means of valves V′ V′ opening upwards into it. Through the top of the air-chamber descends nearly to its bottom a pipe *e*, to the upper part of which is attached the nose or jet used for directing a stream of water on the fire. By the alternate action of the pistons *p p*, water is drawn through the valves V V, and propelled through the forcing-valves V′ V′, precisely as took place with the air in Fig. 10, and when the surface of the water rises above the lower mouth of the pipe *e*, the air in the air-chamber C is confined above the water; and as the water accumulates in the air-chamber, the inclosed air is compressed, and acts with increased elastic force on the surface of the water, thereby forcing a column of water into the pipe *e*, and out through the hose and jet attached to it, with a force depending partly on the degree of condensation, and partly on the elevation of the extremity of the hose above the level of the engine. The pressure of the condensed air has *first* to support a column of water, whose height is equal to the level of the end of the tube above the level of the water in the air-chamber; and until the pressure of the condensed air exceeds what is necessary for this purpose, no water can spout from the end of the hose; and, *secondly*, the force of the jet will be proportional to the excess of the pressure of the condensed air above the weight of the column of water, whose height is equal to the elevation of the end of the hose above the level of the water in the air-vessel. When the air in the air-chamber is condensed into half its original bulk, it will act upon the surface of the water with double the atmospheric pressure; while the water in the force pipe being subject to only one atmospheric pressure, there will be an unresisted upward force equal to one atmosphere which sustains the column of water in the tube; consequently, a column will be sustained or projected to the height of 34 feet. When the air is

reduced to $\frac{1}{3}$rd of its original bulk, the height of the jet will be 68 feet; and so on.

16. The siphon is not a pump, but a bent tube so contrived as to convey liquids from one vessel to another at a lower level, by raising them first *above* their natural level in the first vessel. In Fig. 12, the siphon, or bent tube A B C, has its shorter leg A B immersed in the liquid which is to be transferred from the vessel D to E. At the commencement of the operation, the shorter leg is immersed in the vessel D, and the air removed from the tube by applying the mouth to the extremity C of the longer limb, or the end C may be closed and the air sucked out through an opening at the top of the bend, which is afterwards closed; or, lastly, the siphon may be held with its ends upwards, filled with liquid, the ends closed, turned downwards, and the shorter immersed in D. But in any case, however the siphon may be filled, as soon as this is done, the atmospheric pressure on the surface of the liquid in D forces the liquid up the tube towards the highest point B, and if this point be not at a greater height than about 32 feet if water be employed in D, and not more than 30 inches if the vessel contain mercury, the fluid will pass beyond the highest point B, and fill the whole of the tube to C. The vessel E can then be placed under the open end C, and the whole of the liquid in D situated above the open end A will be transferred into E.

Fig. 12.



The reader will understand why one limb of the siphon must be longer than the other by considering that, when the instrument is left to itself, the atmospheric pressure is acting as much at one extremity of the siphon as at the other. If, when the liquid column is raised to B, the mouth be withdrawn from C, the column will fall back into the vessel D. It will do the same if we get the liquid no further than F,

which is the level of the liquid in D, because at that point the *upward* pressure of the atmosphere prevails over the *downward* pressure of the liquid; but beyond that point, in the direction F C, the downward pressure of the liquid prevails over the upward pressure of the atmosphere, and the liquid will flow out. Thus the motion of the fluid is, as Mr. Webster remarks, similar to the motion of a chain hanging over a pulley. If the two parts of the chain be equal, the fluid remains at rest; and if one end be longer than the other, it moves in the direction of the longer end. Fresh links, so to speak, are added continuously to the fluid chain by the atmospheric pressure on the surface of the fluid, so that the chain being continuous, the motion is continuous also, and does not cease till one portion of the chain becomes equal to or less than the other.

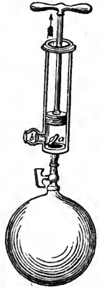
A stream of water descending through the air tapers downwards, and at a certain depth divides into drops, because each particle falls with accelerated velocity, and at length, when it has overcome their cohesion, leaves the other particles behind it. But when the stream is enclosed in a tube, this separation of its parts is prevented by the atmospheric pressure above and below keeping them together and forcing the whole stream to flow with *equal* velocity; the lower part dragging the upper after it, while the upper, by its inertia, equally retards the lower, so that they move together with the mean of their natural velocities; and the discharge is, of course, more rapid than if there were no tube, and will be faster the longer the tube. Now, as the same is true of a stream of light fluid ascending through a heavier, this explains why the draught of a furnace depends on the height of the chimney.

17. The elasticity of the air is taken advantage of in applying it as a stuffing material for cushions, pillows, and beds. A textile fabric is rendered air-tight by the application of a solution of India-rubber, and when made up into the required form, the seams are rendered tight by means of the same substance. At one corner is a short tube, fitted

with a screw, by loosening which the bag can be distended, and by tightening it the air is prevented from escaping. If too much air be introduced, the cushion becomes too hard, but when moderately distended, it forms a tolerably soft surface; when not in use, the air can be let out and the cover folded up into a small space. The principal objection to its use arises from its great heat; air being a bad conductor of heat. The enclosed air, when made warm by the heat of the body, retains its warmth, and produces an unpleasant sensation of dry heat to the part which rests upon it.

18. The action of the air-gun also depends upon the elasticity of condensed air. The exhausting syringe, Fig. 13, may also be used as a condensing syringe. If the vessel be removed from the end of the syringe, and screwed into the short tube *b* at the side, it will be evident that on drawing the piston to the top of the cylinder, air will rush through the valve *a* and fill it. On depressing the piston, the valve *a* will close and the valve *b* will open, so that the air contained in the cylinder will be forced into the vessel through the valve *b*, and if the vessel be strong enough, it will accommodate this increased quantity of air without bursting. On again raising the piston to the top of the cylinder, a fresh supply of air will fill it, and on again depressing the piston, an additional quantity will be forced into the vessel. Each succeeding descent of the piston will, however, become more difficult, for the air contained in the cylinder will not force open the valve *b*, until it is more compressed than the air within the vessel which presses up against the valve *b*. On closing the stop-cock, and removing the vessel from the syringe, we have a volume of condensed air, which will rush

Fig. 13.



out with great force the moment the stop-cock is opened, and this force has been used for projecting balls, or other missiles.

In the air-gun the vessel for containing the condensed air, is a strong metal ball, furnished with a small hole and a valve opening inwards. This ball is screwed to a barrel containing a bullet, when, upon turning a cock, and opening a communication between the condensed air and the bullet, the latter will be projected forward with a greater or less velocity, according to the state of condensation and the weight of the bullet. In air-guns the reservoir of condensed air is usually very large in proportion to the tube which contains the ball, so that its elastic force is not greatly diminished by expanding through it, and the ball is urged all the way by nearly the same uniform force as at the first instant. The elastic fluid arising from inflamed gunpowder, on the contrary, is very small in proportion to the barrel of the gun, and occupies only a very small portion of it next the butt-end; so that, by dilating into a comparatively large space as it urges the ball along the barrel, its elastic force is proportionally weakened, and it acts always less and less on the ball in the barrel. "Whence it happens that air condensed into a pretty large machine only ten times, will project its ball with a velocity but little inferior to that given by gunpowder; and if the valve of communication be suddenly shut again by a spring, after opening it to let some air escape, then the same charge may serve to impel several balls in succession. In all cases where a considerable force is required, and consequently a great condensation of air, it will be requisite to have the condensing syringe of a small bore, perhaps not more than half an inch in diameter; otherwise the force requisite to produce the compression will become so great that the operator cannot work the machine; for as the pressure against every square inch is about 15 lbs., and against every circular area of an inch diameter 12 lbs., if the syringe be an inch in diameter, it will require a force of as many times 12 lbs. as

the density of the air in the receiver exceeds that of the common atmosphere; so that when the condensation is ten times, the force required will be 120 lbs; whereas, with a half-inch bore, it will only amount to 30 lbs."*

There are various forms of air-gun, but perhaps the best is Martin's. It consists of a lock, stock, barrel, ramrod, &c., of about the size and weight of a common fowling-piece; under the lock is screwed on a hollow copper ball, perfectly air-tight. This ball is charged with condensed air by means of the condensing syringe. When the ball is charged and screwed on, a bullet is rammed down in the barrel: if the trigger be then pulled, a pin in the lock will, by the spring-work within, strike into the copper ball, and by suddenly pushing in the valve within it, let out a portion of the condensed air, which, rushing up through the aperture of the lock, and forcibly striking on the bullet, will propel it to the distance of 60 or 70 yards, or further, if the air be strongly condensed. The gun may in this way be discharged many times before the condensed air will have lost its propelling power.†

19. As the barometer is by far the most important instrument connected with Pneumatics, it is necessary to describe its construction somewhat minutely, and to state at some length the amount of information which is to be derived from it.‡

* Encyclopædia Metropolitana, art. Pneumatics.

† The first notice of the modern air-gun is in the Elémens d'Artillerie of David Rivaut, who was preceptor to Louis XIII. of France. He ascribes the invention to Marin of Lisieux, who presented one to Henry IV. It appears, however, that Ctesibius, an Alexandrian Greek, who lived B.C. 150—120, applied the elasticity of the air to the construction of *wind-guns*; but in these machines the ball was not immediately exposed to the action of the air, but was impelled by the longer arm of a lever, while the air acted on the shorter. The air-gun is now seldom used, and indeed it has been regarded chiefly as a scientific toy, except in those cases, which we should hope are of rare occurrence, where it has been made the instrument of private revenge.

‡ In the Introduction to the Study of Natural Philosophy (11), the

The essential part of a barometer is a well-formed glass tube, 33 or 34 inches long, of equal bore, containing pure mercury only, and so arranged that this mercury may be supported by atmospheric pressure, as in Fig. 15 ; all the other appendages being contrivances for protecting the tube and ascertaining the exact height of the mercurial column.

At first sight nothing appears more easy than to fill a tube with mercury and invert its open end into a cup of the same metal, as shown in Fig. 14. There are, however, certain practical difficulties which render the construction of a good barometer a work of great nicety. In the first place mercury is very liable to contamination, from the facility with which it dissolves baser and cheaper metals, such as tin, lead, zinc, and bismuth ; and as the specific gravities of these metals are all much less than that of mercury,* any admixture of them will cause the height of the barometer, as indicated by a column of the adulterated metal, to be greater than in a barometer containing pure metal. There are various methods of purifying mercury, for which we must refer to chemical works ; † but, in addition to these sources of impurity, it was

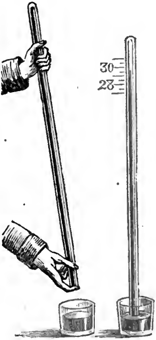


Fig. 14. Fig. 15.

history of the invention is given, together with a notice of the important influence which the discovery of the pressure of the atmosphere had on the progress of science.

* The specific gravity of zinc is 6·8 to 7·2 ; of tin, 7·3 ; of bismuth, 9·9 ; of lead, 11·45 ; and of mercury, 13·56.

† See Faraday's Chemical Manipulation.

the opinion of Sir Humphry Davy, that mercury in its pure state, when exposed to the air, absorbs both air and moisture. If such really were the case, the construction of an accurate barometer would be impossible; but, according to the experiments of the late Professor Daniell, mercury is incapable of absorbing or retaining either air or moisture; and the air-bubbles seen to rise from it when heated or when relieved of atmospheric pressure are merely retained between the mercury and the glass vessel by their attraction for the latter.

On pouring mercury into the barometer-tube and inverting it, the air thus confined between the mercury and the inner surface of the tube will be relieved from atmospheric pressure, and escape into the Torricellian vacuum,* where it will oppose the pressure of the external air, and constantly maintain the mercurial column at a lower level than if the Torricellian vacuum were perfect; so that the observed height of the column would not indicate the true pressure of the atmosphere, but only the excess of the pressure above that within the tube. Now, in order to get rid of this air adhering to the tube, as well as any moisture which is sure to settle upon anything left exposed to the air, it is necessary to introduce small portions of mercury into the tube, and boil them by the action of a small charcoal fire. This, of course, requires considerable care, not only to avoid the fracture of the tube, but also to prevent fumes of mercury from escaping, for these are very pernicious if inhaled. The tube is first gently warmed, so as to dry it thoroughly. A quantity of pure mercury is then poured in, so as to occupy two or three inches of the sealed end of the tube, which is held over the fire until the mercury boils, taking care to turn the tube round upon its axis, so that the heat may be equally applied. After boiling for a minute or

* The vacant space between the top of the mercury and the top of the tube is called the *Torricellian vacuum*, in honour of the inventor of the instrument.

two, the open end is closed by a cork to prevent the introduction of moist air, and the tube is then allowed to cool, in order that the cold mercury which is next to be poured in may not crack the tube. When a second portion of mercury, about equal to the first, has been poured in, the part of the tube containing this new portion is held over the fire until it boils. It is again removed from the fire, and corked up as before. A third portion of mercury is then introduced, and the heat again applied to that part of the tube containing the last addition of metal; and in this way the tube is at length filled, with the exception of a small portion from which the mercury has been expelled by the heat. This is filled up with mercury, and the finger is now placed over the opened end so as carefully to exclude any air; the tube is then reversed into a cup of pure mercury; as the column sinks, it expels the last portion of mercury which had not been boiled; and as there is neither air nor aqueous vapour above the mercurial column, its length exactly measures the atmospheric pressure whenever the temperature is too low for the mercury to give out any sensible quantity of vapour. It appears, however, that mercury exists in the aëriform state whenever its temperature is above 60°, so that it must, in this state (though exceedingly rare), fill the so-called vacuum at the top of the tube, and, by its elasticity, depress the liquid, and partly counterbalance the external pressure. But this source of error, which is unavoidable, is fortunately extremely small.

20. With all the above precautions, however, the barometer is liable to continual deterioration from another cause. Capillary attraction, or that force by which solids attract fluids so as to be wetted by them, does not act equally between all solids and fluids. Most solids, with the exception of certain metals, display less attraction of this kind for mercury than for any other fluid, so that they are never wetted by it, and, when immersed in it, they always retain a film of the last fluid that touched them. Hence

the precautions necessary for removing the film of air from the inner surface of the barometer-tube so as to bring the mercury into contact with the glass; but as this contact cannot be insured on the *outside* of the tube, where it is immersed in the cup, a film of air is always retained on this part of the tube, and also at its under edges, which film creeps by small portions at a time into the interior, and rises up in innumerable bubbles into the vacuum, the film being constantly renewed by the descent of more air between the outside of the tube and the mercury in the cup, and thus the outer air slowly insinuates itself into the barometer. In this way the most carefully constructed barometers have become deteriorated in the course of years, as was shown by Professor Daniell, on a comparison of the registers of the celebrated Meteorological Society of the Palatinate.

In the register kept at Mannheim for twelve years from 1781 to 1792 inclusive, the mean height of the barometer for the second six years is ·062 inch lower than that of the first six years.

In the register kept at Padua, during the same period, the mean of the last six years is ·044 inch lower than that of the first six.

In the register kept at Rome the average of the last six years is lower than that of the first by ·114 inch.

At Buda the difference is ·035 inch. At Brussels ·044 inch. At Munich ·026 inch. From the summit of Peisenberg, a mountain in Bavaria, ·026 inch; and from the summit of Mount St. Gothard, the depression is also ·026 inch.

This irregular and uncertain deterioration of barometers cannot be too greatly deplored, because it vitiates the observations of all those earnest and competent observers, who, during many years, have devoted daily portions of their valuable time to a record of the oscillations of the barometer at various stations. Indeed, until the defect

complained of was remedied by Professor Daniell, the great mass of barometrical observations can scarcely be said to be of any scientific value. The only means of preventing this deterioration of the barometer is by making the bottom of the tube of some substance which attracts mercury in preference to air, so as to be wetted by the mercury. Now, as the metal platinum possesses the rare property of *welding* with glass, that is, of uniting with glass when softened by heat, it occurred to Professor Daniell to unite a ring of platinum with the open end of the barometer-tube, so as to bring it into contact with the mercury, thus effectually preventing the ingress of air into the tube.

21. The same distinguished philosopher also invented a new mode of filling barometer-tubes, which, with far less difficulty and danger, insures as much accuracy as by the old method. The improvement consists in pouring the mercury into the tube while both are under the exhausted receiver of a good air-pump. Care is required to prevent any splashing of the mercury as it descends into the tube, for this causes bubbles of highly-rarefied air to become entangled between the mercury and the glass; this, however, is prevented by pouring the mercury through a long slender funnel extending to the bottom of the tube, and dipping into a small portion of mercury previously introduced, and boiled. By this means all agitation is confined to the tube of the funnel, which, on being removed, and filling up the barometer-tube, the only part containing bubbles is that last filled; and as these bubbles are formed by the highly-rarefied air of the exhausted space, they shrink into invisible points on exposure to the common pressure, and on inverting the tube, the last portion containing these bubbles is expelled, and the tube left perfectly free of air.

In making the standard barometer for the Royal Society, Professor Daniell not only followed this process, but afterwards boiled the mercury still *in vacuo;* and he noticed, as a striking proof of the absence of air and the perfect contact of

the mercury with the glass, that although the bore of the tube was more than half an inch, yet, on inverting it, the fluid did not at once fall to its usual height, but remained suspended to the top of the tube, as water would have done in the same tube, until detached therefrom by a few concussions. Yet this fine instrument, having no platinum guard, as just described, was found after two years to grow dim (like an old looking-glass),* from the insinuation of air-bubbles between the glass and the mercury, so that the tube had to be refilled as before; but, in doing so, a ring of platinum was added to the open end, which has since preserved the instrument from deterioration.

22. As the excellence of a barometer chiefly depends on the absence of all matter except mercury from the tube, we may test its value by three indications:—*First*, by the brightness of the mercurial column, and the absence of any flaw, speck, or dulness of surface; *secondly*, by the *barometric light*, as it is called, or flashes of electric light in the Torricellian vacuum, produced by the friction of the mercury against the glass, when the column is made to oscillate through an inch or two in the dark; *thirdly*, by a peculiar clicking sound, produced when the mercury is made to strike the top of the tube. If air be present in the tube, it will form a cushion at the top, and prevent, or greatly modify, this click.

* Professor Daniell remarks:—"There is a defect which may often be observed in old looking-glasses, which may probably be referred to the same cause as the deterioration of barometers. I allude to a dulness which takes place in large spots over their surface, and which generally seems to radiate from the centre. I have frequently remarked this in the very old mirrors in some of the palaces upon the continent. I imagine that this arises from the slow insinuation of air by the edges, or some accidental crack in the metal at the back of the glass." A damp wall will also produce a similar effect upon looking-glasses, the moisture probably favouring the entrance of the air. See "Elements of Meteorology," vol. ii.: London, 1845. The two essays on the construction and deterioration of barometers, are admirable specimens of patient research, which ought to be studied by every one interested in the subject.

23. The sectional area of the tube is of no consequence to the height of the column of mercury supported. If the sectional area be equal to one square inch, the column of mercury *a b*, Fig. 16, 30 inches high, will be counterbalanced by a column of atmospheric air one inch square, and extending from the surface of the mercury in the cup *b*, to the top of the atmosphere; and as we know the pressure of the air to be about 15 lbs. on the square inch, so the column of mercury, one inch square, in the barometer-tube, weighs about 15 lbs. If, instead of mercury, we take 15 lbs. of water, and form it into a column 1 inch square, we get in such case a height of about 32½ feet. If the sectional area of the tube of the mercurial barometer be only half an inch, the column of mercury will still retain the same height, for it is counterbalanced by the same height of atmosphere, only the column of atmosphere has in this case a base of only half a square inch, instead of an inch. So long, therefore, as the atmosphere presses with the same intensity upon the surface of the mercury in the cup, the column suspended in the tube will be of the same height, whatever its internal diameter.

Fig. 16.

The height of the mercurial column must be measured from the surface of the mercury in the cistern,—from *b*, Fig. 16, for example. Now it will be obvious that the level of this surface must always change with the oscillation of the column: when the atmospheric pressure increases, and the mercury in the tube rises, a portion of the metal is drawn out of the cistern into the tube, and the level of the mercury in the cistern is depressed: so, on the contrary, when the atmospheric pressure diminishes, a quantity of mercury is forced out of the tube into the cistern, and the level of the metal in the latter rises. If, therefore, the instrument be

furnished with a fixed graduated scale adjusted to the top of the column when the distance between it and the level of the mercury in the cistern *a b*, Fig. 16, is exactly 30 inches (this being what is called the *neutral point* of the instrument), it will be evident that when the top of the column sinks to 29 inches on the scale, the distance between the two extreme points will be somewhat less, depending on the capacity of the cistern, in which the mercury rises at the same time that it falls in the tube. So also, if the column rise to 31 inches, the distance will be rather more than this, on account of the additional quantity of mercury drawn into the tube. If the cistern be a section of a cylinder, with a flat bottom, bearing a certain known proportion to the bore of the tube, such as 1 : 100, and the mercury rise 1 inch above the neutral point, then as much mercury will be withdrawn from the cistern as fills 1 inch of the tube; but as the base of the cistern is 100 times greater than the bore of the tube, it is obvious that this inch of mercury in the tube would cause a fall of only $\frac{1}{100}$th of an inch in the level of the mercury in the cistern; or, in other words, the fall of $\frac{1}{100}$th of an inch in the mercury in the cistern is accompanied by a corresponding rise of $\frac{99}{100}$ths in the tube. A similar effect is produced by any other change in the height of the column, so that, if the inches on the graduated scale be made each $\frac{1}{100}$th part less than an inch, the instrument will afford tolerably correct results. In some instruments, however, the scale, accurately divided into inches and parts of inches, is made moveable, and terminates in an ivory point, which is brought down to the surface of the mercury. When this point and its reflection appear to be in contact, the height indicated by the scale is correct. In other forms of the barometer, the mercury in the cistern is always maintained at the same level, for which purpose the cistern is formed partly of leather, so that, by means of a screw at the bottom, the surface of the mercury may always be adjusted to the neutral point before taking an observation. The

cistern is also sometimes provided with a gauge or float, which indicates when the mercury in the cistern is too high or too low. By turning the screw one way or the other, the mercury in the cistern is adjusted to the proper level. When there is no gauge, the relative capacities of the cistern and tube are ascertained and marked on the instrument, together with the neutral point. In an example given by Mr. Belville,* the capacity for every inch of elevation of the mercury in the tube is supposed to be equal to $\frac{1}{40}$, which, reduced to a decimal = 0·025 in. per 1 inch, 0·01$\dot{3}$ in. per ½ inch, 0·007 per ¼ inch.

	Inches.
Then if the observed height =	30·400
And the neutral point be =	30·000
The difference above the neutral point will be	·400
Then add for capacity	+ ·010
The correct height will be	30·410

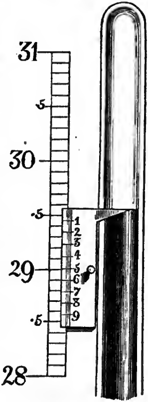
In this case the observed height is above the neutral point; in the following example it is below it:—

	Inches.
Observed height..............	29·500
Neutral point................	30·000
Difference below neutral point..	·500
Subtract for capacity	—·013
Correct height	29·487

24. As the range of the barometer in this country is limited to about 3½ inches, it is not necessary to commence the scale from the neutral point: the divisions usually begin at the 27th inch, and are continued to the 31st. But in instruments intended to measure the height of mountains, or for accompanying balloons, the scale begins at the 12th or 15th inch. Each inch is divided into ten parts, and these are

* A Manual of the Barometer, by J. H. Belville, of the Royal Observatory, Greenwich: London, 1849. This cheap but excellent little work ought to be in the hands of every one who uses a barometer.

Fig. 17.



subdivided into hundredths by means of a small sliding scale, called a *vernier* or *nonius*,* attached to the side of the large scale, as in Fig. 17. It measures exactly one inch and one-tenth in length, and is divided into ten equal parts, numbered from the top downward; while the divisions of the inches of the scale are numbered from the bottom upwards. Now as 10 divisions on the vernier are equal to 11 on the scale, and as these 10 are all equal to each other, it follows that each division of the former must be equal to $1\frac{1}{10}$th division of the latter, or to $\frac{11}{100}$th inch. If, therefore, any division of the vernier coincide, or is in a line with a division on the scale, the two lines immediately above or below those which coincide, will be separated by a distance exactly equal to $\frac{1}{100}$th inch; the pair, two divisions removed from the first, has a deviation of $\frac{2}{100}$th of an inch, and so on. Thus, in Fig. 17, the line marked 6 on the vernier, coincides with the line 28·9 on the scale; but the two lines immediately above them, marked 5 and 29, do not exactly coincide; and this want of coincidence must amount to $\frac{1}{10}$th of $\frac{1}{10}$th of an inch, or $\frac{1}{100}$ of an inch. In the next two lines, marked 4 and 29·1, it will be

* So called from Peter Vernier, a gentleman of Franche Compté, who described it in a tract printed at Brussels, in 1631. The word *nonius* is derived from Peter Nunnez, or Nonius, as his name has been Latinized, a Portuguese mathematician, born at Alcazar, in 1497.

seen that they fail to coincide by $\frac{1}{10}$th of $\frac{2}{10}$th of an inch, or $\frac{2}{100}$th of an inch. In like manner the lines marked 3 and 29·2, 2 and 29·3, 1 and 29·4, and 0 and 29·5, deviate from each other respectively by $\frac{3}{100}$th, $\frac{4}{100}$th, $\frac{5}{100}$th, and $\frac{6}{100}$th of an inch. The same measuring will also apply to the lines situated below the coincident lines marked 6 and 28·9: thus 7 and 28·8, immediately below them, fail to coincide by $\frac{1}{100}$th of an inch, and so on with respect to the others. The point to be attended to is that a division on the vernier is $\frac{1}{100}$th of an inch larger than a division on the scale.

In applying the vernier to measure off small portions of an inch in the height of the barometer, we first notice the height of the column by the fixed scale, which, in Fig. 17, is more than 29·5 inches, but less than 29·6. In order to measure the hundredths of an inch, we place the zero or top of the vernier scale, exactly level with the top of the mercury. We next observe that, of all the lines on the vernier, only one can coincide with a line on the scale. In the figure the line marked 6 on the vernier, coincides with a line on the scale, and as from the top of the mercury to these coincident lines, there are six pairs which do not coincide; and as each pair deviates by $\frac{1}{100}$th of an inch more than the pair below it, the uppermost pair must evidently differ by $\frac{6}{100}$th of an inch. We thus get the height of the mercury in one figure, which is $29\frac{1}{2}$ inches and $\frac{6}{100}$th inch, or, expressed decimally, 29·56.

25. The words "Change," "Fair," and "Rain" engraved on the plate of the barometer, are calculated to mislead; for, as Mr. Belville remarks, "from the observations of two centuries we find that heavy rains, and of long continuance, take place with the mercury at 29·5 inches, or 'Change;' that rain frequently falls when it stands as high as 30 inches, or 'Fair;' and more particularly in winter, a fine bright day will succeed a stormy night, the mercury ranging as low as 29 inches, or opposite to 'Rain.' It is

not so much the *absolute* height as the actual rising and falling of the mercury, which determines the kind of weather likely to follow." Instrument-makers still continue to engrave these words on the scale, apparently for no other reason than old-established usage; their customers would probably think the instrument imperfect without them, just as the readers of "Moore's Almanac" insist upon having the supposed influence of the planets upon the different members of the body entered for every day in the year. Indeed, the defects of the common barometer, as it leaves the hand of the instrument-maker, are so serious as to render this instrument almost worthless to science. "In the shops of the best manufacturers and opticians," says Professor Daniell, "I have observed that no two barometers agree; and the difference between the extremes will often amount to a quarter of an inch: and this with all the deceptive appearance of accuracy which a nonius, to read off to the 500th part of an inch, can give. The common instruments are mere playthings, and are by no means applicable to observations in the present state of natural philosophy. The height of the mercury is never actually measured in them, but they are graduated from one to another, and their errors are thus unavoidably perpetuated. Few of them have any adjustment for the change of level in the mercury of the cistern, and in still fewer is the adjustment perfect: no neutral point is marked upon them; nor is the diameter of the bore of the tube ascertained: and in some the capacity of the cisterns is perpetually changing from the stretching of a leathern bag, or from its hygrometric properties. Nor would I quarrel with the manufacture of such playthings; they are calculated to afford much amusement and instruction; but all I contend for is, that a person who is disposed to devote his time, his fortune, and oftentimes his health, to the enlargement of the bounds of science, should not be liable to the disappointment of finding that he has wasted all, from the imperfection of those instruments, upon the goodness of which he conceived he

had good grounds to rely. The questions, now of interest to the science of meteorology, require the measurement of the 500th part of an inch in the mercurial column; and notwithstanding the number of meteorological journals, which monthly and weekly contribute their expletive powers to the numerous magazines, journals, and gazettes, there are few places, indeed, of which it can be said that the mean height of the barometer for the year has been ascertained to the 10th part of an inch."

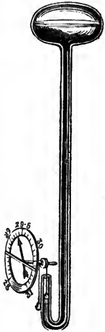
26. The barometer ought to be fixed in a truly vertical position, and if possible with a northern aspect, in order that it may be subject to as few changes of temperature as possible. It is usual, for the sake of comparison, to reduce the observations to 32°, for which purpose tables for correction for temperature are given in scientific works devoted to the subject of the barometer. "The height of the cistern of the barometer above the level of the sea, and, if possible, the difference of the height of the mercury with some standard, should be ascertained, in order that the observations made with it should be comparative with others made in different parts of the country. Before taking an observation, the instrument should be gently tapped, to prevent any adhesion of the mercury to the tube; the gauge should be adjusted to the surface-line of the cistern, and the index of the vernier brought level with the top of the mercury." The application of the barometer as a weather-glass will be noticed hereafter.

27. Various contrivances have been made for increasing the length of the scale, or for making it more convenient for use. The most popular form is the common wheel-barometer, or *weather-glass*, as it is called. In this instrument, the tube, instead of terminating at the bottom in a cistern, is recurved so as to form an inverted siphon, as in Fig. 18. As a rise of the mercury in the longer or closed limb is equivalent to a fall in the shorter limb, and *vice versâ*, a float is placed on the surface of the mercury in the shorter limb,

and is connected with a string passing over a pulley, and very nearly balanced by another weight on the other side of the pulley. An index hand attached to the pulley moves over the surface of a dial-plate, graduated so as to indicate the oscillations of the mercurial column. With an increase of atmospheric pressure the mercury in the longer tube rises, and that in the short tube is depressed, together with the float, and this gives a small motion of revolution to the pulley, and also to the attached index hand. A fall in the longer column causes the mercury with its float in the short limb to rise, and consequently moves the index hand in the contrary direction.

The siphon form of barometer, as commonly made, is inferior to the cistern barometer, because a change of pressure, such as would make a difference of nearly an inch in the upper level of the latter, would show but half an inch in each level of the siphon; for although the surfaces of the mercury in the longer and shorter limbs would be an inch farther apart, that inch would be compounded of a rise of half an inch at one surface, and a corresponding fall at the other. The unit of measure, therefore, becomes only half as great, and necessarily diminishes in utility. In our figure, however, the upper end of the tube is expanded into a bulb, in order that, by enlarging the upper surface of the mercury, the difference of level may be made to depend almost entirely on the lower surface, giving the same advantage as in a common barometer with a cistern of the same horizontal area as the bulb.

Fig. 18.



28. The desire to produce a more delicate measure of the atmospheric pressure has led to the

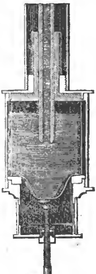
construction at various times of a *water-barometer*, the lower surface of the water being protected from direct contact with the air by a layer of some more permanent liquid, such as oil, or some elastic solid, such as India-rubber. Soon after the invention of the barometer, a water-barometer was constructed by Otto Güricke (the inventor of the air-pump), and afterwards by Mariotte. It was supposed that the greater range of its oscillations would measure more minute changes of pressure. An instrument of this kind was constructed by Professor Daniell for the Royal Society. It consists of one entire tube of glass, which was drawn out to the length of 40 feet without much difficulty. Its diameter is about an inch, and the average height of the fluid column 400 inches. When originally put up in the year 1832, the water in the cistern was covered with a layer of castor oil; but as that did not prevent the admission of the outer air, it was found necessary to refill the tube. This was done in January, 1845, and a solution of caoutchouc in naphtha was substituted for the castor oil. In windy weather this barometer appears to be constantly fluctuating, indicating numerous changes of pressure, which have no sensible effect on the most delicate mercurial barometer; the column appears to be in a state of perpetual motion, compared by Professor Daniell to the slow act of respiration. But the most important result is, that this instrument precedes by one hour the mercurial barometer of half an inch bore, as this does the mountain barometer of 0·15 inch bore, by the same interval in their horary oscillations; showing that, while philosophers are disputing about the hours of the maxima and minima, much depends upon the construction of the instrument observed.

29. For the measurement of heights, and as a companion for the scientific traveller, the barometer has been made portable. The portable barometers of Gay Lussac, of Troughton, and of Fortin, are those best known. In making an observation, the barometer can be hung to the upper part of a

tripod stand, as in Fig. 19, the stand itself serving as a secure case for packing and conveying the instrument. Gay Lussac's barometer is of the siphon form; that of the other two makers is what the French call *à cuvette*, that is, with a cistern. As the level of the mercury rises or falls in the tube, it falls or rises in the cistern, and in order to measure correctly variations in the length of the column, these two changes of level must be attended to, as already explained (23). For this purpose, the bottom of the cistern is moveable; it is formed of leather, and rests upon the flat extremity of a screw *a*, Fig. 19, and shown on a larger scale in Fig. 20. By turning this screw in one direction, the bottom of the cistern will evidently be raised, and in the other direction lowered, and the level of the mercury in the cistern will undergo a corresponding change. Hence this level can always be adjusted to the neutral point before taking an observation, so that the variations in the mercurial column may truly represent variations in atmospheric pressure. To facilitate this operation, the cistern is furnished with an ivory point, which descends exactly to

Fig. 19.

Fig. 20.



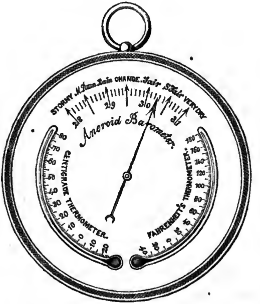
the level of the zero, or neutral point of the scale, and the mercury is screwed up or down until the real and the reflected ends of the ivory appear to coincide; or, as in Fig. 20, which represents the cistern of Troughton's instrument, the screw is turned so as just to exclude the light from passing between the surface of the mercury and the upper edges of the slits in the brass cover with which the cistern is provided, the upper edges of the slits representing the commencement of the scale of inches. The tube is also inclosed in a brass case, the lower part of which contains a thermometer. The divided scale commences at 15 inches above the neutral point, and is continued as high as 33 inches, each inch being subdivided into 1,000 parts by means of a vernier, *c*, Fig. 19. A slit from end to end of the divided scale exposes the glass tube and the mercury. In taking the height of the mercury, the vernier point is brought down so as just to exclude the light from passing between it and the spherical surface of the top of the column of the mercury. In order that the observation may be correct, it is necessary that the barometer be exactly vertical, for if inclined, the space occupied by the mercury would have a somewhat greater length than that which is really due to atmospheric pressure. The head of the tripedal staff is therefore constructed somewhat in the same manner as the gimbals which support a compass-bowl or a chronometer. The application of this instrument to the measurement of heights will be noticed further on (56).

30. An instrument named the *aneroid* * *barometer* has been invented by M. Vidi of Paris. Its action depends on

* From two Greek words, signifying without fluid, *i. e.*, neither mercury nor water is used in its construction.

the effect produced by the pressure of the atmosphere on a metallic box deprived of air and hermetically sealed. An index traversing a dial, Fig. 21, records the changes in the weight or pressure of the air on a given surface. It is $4\frac{3}{4}$ inches in diameter across the face, and $1\frac{3}{4}$ inch thick. It is graduated to correspond with the mercurial barometer,

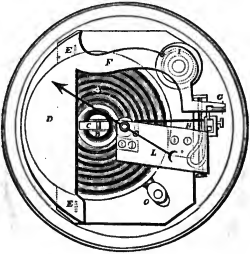
Fig. 21.



and two small thermometers are fixed on the face of the dial, one graduated according to the Centigrade and the other after Fahrenheit's scale. Fig. 22 shows the internal construction, as seen when the face is removed, but with the hand still attached. A is a flat circular box of white metal, about $\frac{1}{4}$ inch in depth, with the surfaces corrugated in concentric circles, to give it greater elasticity. This box being exhausted of air through the short tube *o*, and then made air-tight by soldering, forms a spring, which is affected by every variation of pressure in the external air. This box

is attached to the bottom of the metallic case which incloses the mechanism of the instrument. At the centre of the upper surface of the elastic box is a solid projection, C, about half an inch high, to the top of which the principal lever D F I is attached. This lever rests partly on a spiral spring at I, and is also supported by two vertical pins,

Fig. 22.



with perfect freedom of motion. The end G of the principal lever is attached to a second or small lever, from which a chain, H, extends to the centre, where it works on a drum attached to the arbour of the hand. A hair-spring, the attachments of which are made to the metallic plate L, regulates the motion of the hand.

As the weight or pressure of the atmosphere is increased or diminished, the surface of the elastic box A is depressed or elevated, and this motion is communicated through the levers to the arbour of the hand. The spiral spring, on which the lever rests at I, is intended to compensate for the effects of alterations in temperature of the minute portion of air which the box must contain, however perfect

the exhaustion. The actual movement at the centre of the elastic box, from whence the indications emanate, is very slight; but this is increased 657 times at the point of the hand; so that a movement to the extent of $\frac{1}{22}$nd part of $\frac{1}{10}$th of an inch in the box carries the point of the hand through 3 inches on the dial. The tension of the box in its construction is equal to 44 lbs. At the back of the outer case is a screw to adjust the hand to the height of a standard mercurial barometer.*

31. There are other barometrical instruments of greater or less utility, which have been introduced at various times for measuring the absolute pressure or elasticity of any fluid in which they are placed. We must refer to larger treatises for an account of these instruments, but we may notice the principle upon which certain instruments, called *differential barometers*, are constructed. They consist essentially of a portion of liquid placed in the bend of a siphon tube shaped like the letter U, having its two ends open to the two fluids whose pressures are to be compared. The *difference* of these pressures causes a depression of the liquid in the leg exposed to the greater pressure, and an elevation in the other leg; the column of liquid thus sustained balancing the excess of pressure on the lower level above that on the upper. The difference of pressures is exactly measured by the difference of these levels.

Such an instrument, with mercury as the measuring fluid, forms the common *mercurial gauge* used for showing the elasticity of steam in the boiler and other parts of a steam-engine. One end of this tube, A, Fig. 23, being inserted in the boiler, cylinder, or condenser, and the other end being open to the air, the rise of the mercury in the outer limb shows the excess of the elasticity of the steam above that of the external air; or, with another form of instrument, where the inner limb next the boiler is twice the length of the outer, its depression in the outer limb, and its rise in

* Redwood, Pharmaceutical Journal.

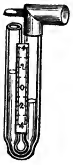
the inner, show the excess of the atmospheric pressure over that of the uncondensed vapour remaining in the condenser; or over that of the low-pressure steam, when such is used. In either case, as the support of 30 inches' difference of level in the mercury requires a pressure, or difference of pressures, equal to the atmospheric pressure, or about 15 lbs. per square inch, the difference of pressures will always amount to about half as many pounds per square inch as there are inches between the two levels of the mercury. A scale attached to the gauge indicates the amount of pressure at a glance.

Fig. 23.

The use of steam of very high elasticity in marine, and especially in locomotive engines, requiring the extension of this instrument to an inconvenient length, has led to the substitution of *spring-pressure gauges*, which, although free from the inconveniences of the mercurial gauge, are inferior in principle, because, as every spring is constantly weakened by use, the value of the scale of these instruments must be constantly changing.

32. When the difference of the pressures to be compared is very small, the difference of level in the mercury is not easily measured; all that is necessary to increase the delicacy of the instrument is to substitute a lighter liquid, such as water, which being, as we have seen (13), raised nearly fourteen times higher than mercury by the same pressure, renders the indications nearly fourteen times more delicate. This simple instrument, a siphon tube, Fig. 24, containing a little water, was applied by Dr. Lind as an *anemoscope*, or *wind-measurer*, one end of the siphon being bent horizontally, so as to face the wind. The two limbs of the tube were each about 9 inches long, and $\frac{4}{10}$ths of an inch in diameter, and

Fig. 24.



they were connected at their lower extremities by a smaller tube $\frac{1}{10}$th of an inch in diameter, for the purpose of retarding the quick oscillations of the fluid by irregular blasts of wind. A scale of inches is placed between the two limbs, the zero corresponding to the level of the fluid in both tubes when subjected to equal pressures. In our figure the two levels being each $1\frac{1}{2}$ inch from zero, their difference is equal to 3 inches. It was found by this instrument, that the difference of pressures on the windward and leeward sides of any object, even in the greatest gales, bears but a very small proportion to the whole pressure, for, while the latter is capable of supporting from 29 to 30 inches of mercury, or from 32 to 34 feet of water, the column of water supported in the wind-gauge never exceeds a few inches. While the average pressure of the air in all directions, therefore, amounts to $14\frac{1}{2}$ or 15 lbs. on a square inch, or above 2,000 lbs. on a square foot, the difference of this pressure in different directions, produced by wind, never exceeds 15 or 20 lbs. on the square foot, even in the greatest storms of our climate.

As this difference of pressures bears a simple relation to the velocity of the wind, the latter is easily calculated from it; and in this manner the following table has been constructed, to show the velocity and the pressure on a square foot of surface corresponding to different heights of water supported in the gauge, and to different familiar designations of the intensity of wind.

Designation of wind.	Velocity in miles per hour.	Inches of water supported.	Pressure on a square foot.
Gentle breeze	3·25	0·01	0·83 oz.
Pleasant breeze	6·5	0·04	3·33 oz.
High wind	16·25	0·25	1 lb. 5 oz.
Storm or gale	32·5	1·	5 lbs. 3 oz.
Great storm	56·29	3·	15 lbs. 9 oz.
Hurricane	79·61	6·	31 lbs. 3 oz.
Tremendous hurricane	97·5	9·	46 lbs. 12 oz.

Hence it appears that the pressure increases as the *square* of the wind's velocity, as will be seen by comparing either of the two latter columns of the table with the second.

This simple and elegant instrument has, like the mercurial steam-gauge, been superseded by the more manageable but less accurate measure afforded by the compression of a spring. Machinery connected with such a spring has been made to move a pencil over paper, so as to keep a continual register of the variations in the *intensity* of wind as well as in its *direction;* and the registers so kept for the last few years have elicited some remarkable facts in meteorology, and must conduce greatly to its progress. A fine *anemometer*, or machine of this kind, is erected on the roof of the Royal Exchange in London, and is made to register its indications in a room below.*

33. There are a few other sources of error, in addition to those already mentioned, for which allowance must be made in estimating fluid pressures. One of these is the effect of *capillarity* already alluded to. In the water-barometer capillary attraction raises the water somewhat higher in the tube than is due to pressure alone, but in the mercurial column it is somewhat lower, so that in nice observations a correction has to be made for capillarity.

In a tube of small bore, when the mercury is *rising*, its surface is convex; when it is *falling*, it is concave, as if the centre of the fluid column always preceded the sides in all its motions; as the centre of a river or of a glacier moves faster than its sides, which are retained by friction against the banks.

Another effect is due to heat, the general tendency of which is to expand all bodies. Hence a rise in the barometric column may be due to increased atmospheric temperature, and not to increased pressure; but as this will also operate on the graduated scale, and also on the glass of the barometer tube, these different expansions may, to a certain

* See the Essay on Anemometry, in the Appendix.

extent, correct each other. But as solid metals, such as the scale is made of, and mercury and glass, expand unequally from the effects of temperature, it is necessary, in very nice observations, to apply certain corrections : for common purposes, however, these corrections may be neglected.

34. This leads us to the consideration of the effects of temperature upon aëriform bodies.

Under ordinary circumstances the elastic force of air varies in the same ratio as its density, provided, however, that its temperature remains unchanged. This element must always be taken into account in all comparisons of density and elasticity, because change of temperature in any body is necessarily attended by a change in the relations of its density and elasticity. When, therefore, it is stated that an increase of temperature produces an increase in the bulk of a body, or, in other words, a diminution of its density, we suppose its elasticity to remain unaltered, which would necessarily be the case if always confined or prevented from further expansion by the same degree of pressure, such as the common atmospheric pressure. An alteration of this pressure, however, even although amounting to its entire removal, or to its increase several times, produces so little change in the density of solids and liquids, compared with the change produced by a single degree of temperature, that these changes may be totally neglected in stating the effects of heat on those bodies. But the case is very different with gases, and we now proceed to study the simple and beautiful relations between their properties and their temperature.

As any change of density is accompanied by a similar proportional change of elasticity when the temperature remains constant, so any changes of density and of temperature are simply proportional to each other when the elasticity remains constant, and so also are all changes of temperature and elasticity proportional to each other when the density remains constant. Any one of these three elements being unchanged, the changes of the other two are proportional to

each other; no one element of the three can be altered without altering one of the others, but it may be either one; and when any two of them are constant, the third is also constant: so that, any two of them being given, the third is known.

Hence an increase of temperature does not necessarily cause bodies to expand, for this expansion may be restrained by the application of sufficient pressure; but this pressure is, in the case of solids and liquids, so great, or, in other words, their increase of elasticity is so great, for small increments of heat (supposing their bulk to remain constant), that probably no available amount of mechanical force could sensibly prevent their expansion. But the expansion of air is to some measurable extent impeded by the smallest measurable pressure; and even a change of pressure that would double its bulk may be prevented from causing any expansion, by inclosing the air in a vessel of moderate strength. But as air, however small in quantity, always fills the vessel in which it is inclosed, it is evident that no change of temperature can in this case alter its bulk except by bursting the vessel. If the vessel be strong enough to prevent this, the inclosed air, although its density be unaltered, must have the repulsive force of its particles, that is, its elasticity increased by increase of temperature; so that, if the elasticity of the external air remain unchanged, the vessel will have to bear a greater pressure on its inner than on its outer surface; and when the difference of these two pressures becomes greater than its cohesion, it will burst, as happens with an inflated bladder held near the fire. The warm air thus liberated suddenly expands, until its elasticity becomes equal to that of the surrounding cold air, although its density is less than that of the latter, so that it will ascend through it.

35. When, therefore, it is said that portions of air and of gas expand like other bodies by heat and contract by cold, it

must always be remembered that this is true only when their elastic force remains unaltered. Otherwise, whatever change any degree of heating or of cooling may produce in their bulk when the elasticity is unaltered, it will produce the same change in their elasticity when their bulk is unaltered. To render the effect of expansion visible and measurable in these bodies, they must be confined in such a way that their elasticity may always balance a constant pressure, or a constant height of some liquid. To effect this requires much care and accuracy; but, from very exact experiments made in this way, the expansion of airs has been found to present the three following remarkable features:—

First. They are more expansible for a given increment of heat than either solids or liquids. For example, steel is increased in length only $\frac{1}{1050}$th, or in bulk only $\frac{1}{350}$th, by being heated 180° from the temperature of melting ice to that of boiling water. But in the case of liquids mercury expands about $\frac{1}{50}$th, water about $\frac{1}{22}$nd, and oil about $\frac{1}{13}$th of its bulk by the same increase of heat. Air, however, is expanded by the same change (its elasticity remaining constant), no less than $\frac{3}{8}$ths, so that 8 measures of air at the freezing temperature become 11 at the boiling point of water.

Secondly. That, although each solid and each liquid has its own peculiar rate of expansion, yet *all* gaseous bodies have the very same rate of expansion, namely, that above stated, which applies to all gases as well as to atmospheric air.

Thirdly. That, while all known solids and liquids expand in an *increasing* rate or with greater rapidity the more they are heated, airs on the contrary seem to preserve an *equable* rate of expansion at all temperatures, their increase of bulk, for example, being the same from 0° or zero to 100° as from 100° to 200°; and as their expansion from 32° to 212° Fahrenheit amounts to $\frac{3}{8}$ths of their bulk at 32°, it follows that every degree on this scale corresponds to a

change in their bulk amounting to $\frac{1}{480}$th* of the bulk at 32° (supposing their elasticity unchanged); but if their density remain constant (as when they are confined in a given space), then each degree of Fahrenheit alters their elasticity by $\frac{1}{480}$th of whatever the elasticity would be at 32°.

Hence, if the temperature of any gas be estimated from an imaginary zero 480° below the freezing point of water on Fahrenheit's scale, or 448° below Fahrenheit's zero, the temperature so reckoned will be *directly* proportional to the elasticity of the gas when its density is unchanged, or inversely proportional to the density when the elasticity is unchanged; or, when either of these two elements is constant, the other varies in the same ratio as the temperature on Fahrenheit's scale, augmented by the constant quantity 448°.

If we know the numerical measure of the density corresponding to a given elasticity at a given temperature, we can then find under any other circumstances the value of any one of these three elements when the others are given. In the case of common air these data have been measured most accurately by Dr. Prout, who found that when its temperature is 32°, and its elasticity balances the pressure of 30 inches of mercury, its density is such that 100 cubic inches of space contain 32·7958 grains troy of it.

The relation of these data is different in different gases. Thus, when common air and chlorine have the same temperature and the same elasticity, the chlorine is two and a half times as dense as the air; while, on the other hand, air is more than fourteen times denser than hydrogen of the same temperature and elasticity. Hence the reason that a balloon ascends when filled with hydrogen, which is necessarily of the same elasticity as the air which presses on it. But in order to render the densities of these three gases equal, the hydrogen must have fourteen times the elasticity of the air,

* The reader will easily perceive that this number is obtained by dividing 180 (the number of degrees between 32° and 212° Fahr.) by $\frac{3}{8}$. Recent experiments, however, assign the fraction $\frac{1}{492}$ or $\frac{1}{493}$, instead of $\frac{1}{480}$.

and this must have two and a half times the elasticity of the chlorine (supposing their temperatures equal). But in every gas the same simple relations subsist between these three properties; so that, when the temperature is reckoned from —448°, then any two of the three (*temperature*, *elasticity*, and *density*) are proportional, when the third is unchanged.

36. In order to gain clear ideas of the relations subsisting between the temperature, the elasticity, and the density of aëriform matter, it is necessary to limit our attention to a volume of air confined in a close vessel, or in a tube such as that by which the *law of Mariotte* was illustrated (9). It is obvious that these relations or laws could never have been discovered by studying the effects of heat on the atmosphere itself; but having once established them by experiment, the natural philosopher knows by analogy that what is true on the small scale of experiment is equally true on the grand scale of nature. Experiments form a sort of index to the volume of creation; they guide us in our search by telling us what to look for; and, confiding in the constancy of nature's laws, the natural philosopher ascends from a few experiments with glass tubes and a little mercury to grand and comprehensive generalizations.

But, before we can understand the effects of heat upon the atmosphere, it is necessary to study another relation between heat and air.

37. All fluids are very bad *conductors* of heat, that is, the amount of heat which is capable of passing from particle to particle without disturbing their relative position is almost inappreciable. But the perfect fluidity and great expansive power of air renders it a most admirable *conveyer* of heat.

We may illustrate the difference between conduction and convection by comparing the action of heat on a solid with that on a liquid. If one end of an iron rod be placed in the fire, the heat will travel to the other end just as quickly whether the rod be inclined upwards or downwards. It will also travel very quickly *upwards* through a tube of water,

but it will not travel *downwards*, or, if it does travel at all downwards, it will be so slowly, that a lump of ice sunk to the bottom of the tube will not be melted, although the water at the surface is boiling, as shown in Fig. 25. Hence water is called a bad *conductor* of heat; but it is a good *conveyer* of heat, as may be proved by applying the heat *below* the tube. The particles of water at the bottom immediately expand by the heat, become lighter than the parts above them, and rise up to the surface, while the cooler and consequently heavier portions descend and occupy their place; they in their turn become heated and ascend, while another set of cooler and heavier particles descend, and thus a constant circulation of *currents* is established until the whole of the water attains the boiling point. But when heat is applied at the surface, no such currents are established, the upper layer becoming heated without communicating much, if any, heat downwards.

Fig. 25.

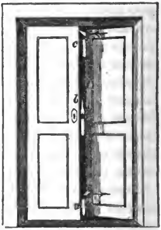
It may be supposed that such an experiment as this does not apply to the atmosphere heated by the warm rays of the sun. It does, however, apply with the greatest strictness. The rays of the sun are not warm in passing through transparent media, such as air; they give out no appreciable heat until they are arrested by some body capable of receiving them, and then, and not until then, is any warmth experienced. Even at the equator the air receives comparatively no heat from the powerful vertical rays of the sun above, but is heated almost entirely from below by the surfaces on which it rests, which are made hot by the rays which have passed through the clear air without any heating effect. This beautiful provision is necessary to give motion to those horizontal currents which produce *wind*, and those ascending and descending currents which mingle all

the particles of air, and tend to preserve its purity, and to equalize the distribution of heat throughout the atmosphere. If the atmosphere were heated from above instead of from below, it would arrange itself in layers as fixed and determinate with respect to each other as those of a sedimentary rock, only increasing in density by night and expanding by day; all then would be a universal calm; there would be no cool gales from the temperate zones to mitigate the heat of the torrid or the cold of the frigid regions; the one would be desolated by heat and the other by cold, and both alike uninhabitable.

But as the solar rays are vertical at only one spot at a time, and become more and more oblique as we recede from that spot, every gradation of temperature is experienced from 120° above to 50° below zero. If we suppose two spots on the earth's surface, one situated vertically under the sun, and the other receiving his rays obliquely, and consequently with less heating effect, the greater expansion of the air over the former spot will cause it to extend altogether to a greater height; but this will not influence the barometer, because, although thére is a greater height of air on the warmer spot, there will be the same absolute quantity on both. But as it is impossible for a fluid to remain thus heaped up in one spot without tending to assume a level surface, the heap of air above the warmer spot will overflow and spread over the colder, thus causing an accumulation of more air on the colder place than on the warmer, and the barometer will rise at the one place and fall at the other. But as the lower stratum at the cold spot will thus be more elastic than that at the warm spot, the former will immediately rush into the latter until their elasticities are equalized. This motion constitutes *wind.* The equatorial regions being constantly more heated than the polar, the atmosphere above the former (independently of centrifugal force) must always extend higher than over the latter, and its upper portions must always be overflowing and tending to produce

a level surface which is never attained. But this upper current *from* the equator is supplied by another current at the earth's surface, flowing with equal constancy *towards* the equator. Indeed, these contrary currents exist on a small scale in every room in which a fire is burning; but they may be best illustrated in two adjoining rooms, in one of which is a good fire, while in the other there is none. If the door between the two rooms be partially opened, the cold air will enter the heated room in a strong current; at the same time the heated air of the warm room ascends and passes the contrary way into the cold room at the upper part of the same doorway, while in the middle of this opening, exactly between the two currents, the air appears to have little or no motion. On holding a lighted candle near the bottom of the doorway, where the air is most dense, as at *a*, Fig. 26, the flame will be strongly drawn towards the heated room; and, if held near the top of the door, as at *c*, it will be drawn towards the cold room with somewhat less force, while midway between the top and bottom, as at *b*, the flame will scarcely be disturbed. Cases of this kind are illustrations of the convection of heat, similar to that which takes place in a boiler; and a similar process is carried on in the great aërial ocean, the whole mass of which is kept in perpetual circulation by the partial application of the sun's heat. An upper current of warm air is constantly flowing from the equator towards the poles to supply the place of the lower current, which flows in the contrary direction near the earth's surface, and forms, in certain latitudes, what are called the *Trade-winds*.

Fig. 26.



38. The tendency to the equalization of elasticity and of

heat in the atmosphere, or, in other words, to equality of pressure in all parts of the same horizontal stratum, and to equality of heat in all parts of the same vertical column, is the cause of all winds, however they may be modified by local circumstances. Equalization of heat, however, does not imply an equal temperature. The quantity of heat required to effect a given change of temperature in a given portion of air depends on its bulk rather than on its weight, because the specific heat or capacity of air becomes greater the more it is rarefied; so that by suddenly rarefying a portion of air its temperature is instantly lowered, and when suddenly condensed its temperature rises; the new temperature thus acquired being, however, in each case only momentary, because the equilibrium of temperature is immediately restored by the surrounding bodies. But this change of temperature is permanent when produced by the removal of a portion of air from a denser into a rarer stratum, or *vice versâ*. Thus if a portion from the earth's surface could be transported to any height, so as to be relieved of a portion of the atmospheric pressure, its consequent diminution of *elasticity* would be more rapid than that of its *density*, because this diminished elasticity is due, not only to diminished density, but also to diminished temperature: the result is an increased capacity for heat, whereby it requires more heat than before to preserve its temperature unchanged; but it obtains no additional supply, because all the surrounding air is as cold as itself. The normal or equilibrial state of the atmosphere as regards heat is not, therefore, a state of equal temperature throughout its height, but a temperature gradually diminishing upwards, according to a simple mathematical law; the fall of temperature being equal for every equal height ascended, and on an average it is very nearly 3° of Fahrenheit for every 1,000 feet.

This explains the changes of climate so beautifully exhibited in miniature on the slopes of mountains, where within a few miles are brought together those varieties of

nature usually spread over many degrees of latitude. Thus on the sides of the Andes or other intertropical ridges, the scenery of every zone is found, and the traveller in the course of a couple of days passes in review the whole scale of vegetation; from matted forests impervious to the sun, filled with the aroma of gums and balsams, and resounding with the din of animal life, he passes by imperceptible gradations into the peaceful woods of a temperate region, where the trees, as he continues to ascend, become smaller and less crowded; these are gradually succeeded by shrubs, low herbage, mosses, and lichens, until at length he enters upon those awful solitudes of snow, where organic life appears extinct.

39. This striking succession of changes is explicable if we bear in mind that the mean temperature of the equatorial atmosphere (which at the sea-level is 82°) is diminished 1° for every 333 feet of ascent; so that at the height of 50 times 333, or 16,667 feet, the mean temperature is reduced to 32°, that is to say, it is as often below as above the freezing point; and, as there is no variety of seasons near the equator, it of course freezes every night at this elevation; so that, while there is an eternal summer in the plains, there is an eternal winter on the mountain-tops. Indeed, it is found that no summit exceeding 15,700 feet is ever free from snow.

The distinct line formed by the lower boundary of the snow on mountains furnishes us with a *natural register thermometer* on a stupendous scale, as Professor Daniell appropriately names it, a scale of which each degree occupies more than 300 feet measured vertically. Except at the equator, this line of course rises in summer and falls in winter, the difference produced by seasons being increased the farther we advance towards the poles. The lowest position of the snow-line depends, of course, on the winter temperature, which diminishes immediately from the equator, very slowly at first; so that this limit, which at no place

within the tropics descends much below 15,000 feet, afterwards declines so much as to meet the sea-level at about the 40th degree of latitude, while in all latitudes above this, frost and snow occur in winter, even at the sea-level. But the highest position of the *snow-line*, or that limit above which it never thaws, must of course depend on the summer temperature. This line coincides with the former only at the equator, and, instead of declining immediately therefrom, it even rises a little towards the tropics, because their *maximum* or *summer* heat exceeds the *constant* heat of the equator. Beyond these limits, however, the line of perpetual snow regularly descends, until in the central latitudes of Europe (on the Alps for example) it is reduced to 8,000 feet, on the Norwegian mountains to 5,000, and in the Arctic Regions it descends to the sea-level.

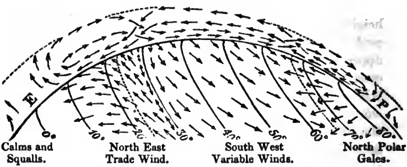
Thus we see that a certain rate of upward diminution of temperature is necessary to the atmospheric equilibrium; but this diminution of temperature produces no currents, because the upper strata, notwithstanding their coldness, have no tendency to descend, nor the lower and warm strata to ascend, because in changing their position they would also change their temperature. Currents can only be set in motion by a still greater inequality of temperature, by the lower strata becoming still warmer, and the upper still colder than the heat equilibrium requires. Now, there is a constant tendency towards such an increase of inequality, because the lower strata are constantly in the daytime receiving heat from the earth or sea, made hot by the solar rays, while the upper strata are losing heat by radiation into space, the constant temperature of which is supposed to be 58° below Fahrenheit's zero.

40. From this view of the atmosphere we are able to understand the wonderful and beautiful contrivance by which the winds of the temperate zones are made to mitigate the extremes of temperature, both in the tropical and the polar regions. It might be thought that the prevailing

winds next the earth's surface could not have this doubly beneficial tendency, but that they must *always* blow from the colder of two parallels into the warmer, as is the case with those currents which produce the trade-winds. We must now inquire why this law is reversed in nearly all places between the latitudes of 30° and 60°, as in this country and all over Europe, for example, where the prevailing winds blow from warmer into colder latitudes. It has been already stated (37) that the immediate effect of a difference of temperature between two adjoining columns of air is to make the warmer column overtop and overflow the colder. In fact, all the upper half of the warmer column (or the half in respect of *quantity*, not *height*) is rendered denser and more elastic than the corresponding parts of the cold column; but this difference of elasticity, which is greatest at the top, diminishes downwards to a certain point where the pressures of the two columns are equal, and consequently there is no wind either way. Below this the difference is reversed, the colder column being the more elastic, and therefore flowing into the warmer more and more strongly as we descend. The trade-winds are thus accompanied by an exactly equal counter-current from the equator in the upper half of the atmosphere; the existence of such a current, exactly opposite in direction to that below, being abundantly confirmed by travellers who have ascended the Peak of Teneriffe, or that of Owhyhee, the only insular mountains sufficiently high to reach the upper current. The summits of most of the West-India islands, however, approach the neutral line of separation between the two currents. Indeed, the trade-winds appear to be so much diminished there as to be inappreciable above the level of 3,000 feet, although the other current cannot be felt below 12,000 feet. The effects of the upper current were strikingly displayed in the volcanic eruption at St. Vincent, in 1812, the ashes of which were carried to Barbadoes; and those of Cosiguina, a volcano in central America, have been conveyed

to Jamaica in direct opposition to the course of the constant trade-wind. Light clouds also, which float at a greater height within the tropics than elsewhere, frequently give evidence of the same fact. Now it is obvious that this upper current, constantly losing heat by its exposure to open space, must, after travelling a certain distance, become cold enough to descend, and change places with the lower current. This change appears to take place usually about the 30th parallel of latitude in each hemisphere, which is accordingly the outer limit of the trade-winds. Beyond this the equatorial current is undermost, and continues to be so until it again becomes by contact with the earth sufficiently warmed to resume its original position above the colder current that proceeds from the polar regions. It will of course be nnderstood that the number of these changes that may occur between the 30th parallel and the pole will depend on difference of season, the amount of radiation from the sun and from the earth, the screening effect of clouds, and many other local circumstances, and hence the proverbial *inconstancy of the winds* over the cooler half of each hemisphere; an inconstancy arising, not from the absence of exact laws (for these winds are regulated by laws as fixed as those which apply to any other terrestrial phenomena), but from the presence of so many disturbing causes, which, as they cannot be anticipated, so they cannot be taken into account in attempting to generalize the phenomena of these winds,—a circumstance which clearly exhibits the folly of those half-informed persons who construct weather-almanacs for predicting atmospheric changes a year in advance. The superior return current from the equator having descended at about the 30th parallel commonly continues to be the lower current or prevailing wind until it approaches the polar circle, where it again rises and is replaced by the *polar gales*, which prevail in high latitudes. These are caused by the cold and dense air of the polar regions sinking and spreading in every direction, being overflowed by an ingress

Fig. 27.



of warmer air from every side, which supplies a constantly descending cataract of air upon the pole the exact converse of the effect at the equator.

These effects are embodied in one view in Fig. 27, which represents a quadrant of the atmosphere between the pole P and the equator at E. At E the heated air ascends and forms the upper current until it reaches about the 30th parallel, where it descends and forms the lower current, which it continues to do until it approaches the polar circle, where it again rises. At the pole P the arrows are intended to represent the polar gales descending and forming the lower current. On leaving the polar circle, they are displaced by the warmer return current from the equator, and, rising above this, descend at about latitude 30°, and proceed to the equator, forming the constant north-east trade-wind in the northern hemisphere, and an equally constant south-east trade-wind in south latitudes.

41. But it may be said that this flow of air from the poles to the equator ought to produce a constant north wind in the northern hemisphere, and a constant south wind in the southern hemisphere, at least within a certain limited distance of the equator, probably below the latitude of 30°, or over the warmer half of the earth's surface. The reason why we do not find this to be the case is on account of the motion of the earth on its own axis from west to east. The

earth being a sphere, the different parts of its surface must, of course, move with very different velocities. At the poles the motion is nothing, but at the equator it is 1,042 miles an hour: in the latitude of 30° it is about 900 miles an hour; so that in the belt between the equator and latitude 30°, the average velocity may be stated at 980 miles an hour, while the space lying between 30° and 40° does not move at a greater rate than about 850 miles an hour.

Now, as the atmosphere may be regarded as an integral portion of the earth's surface moving round with it with the same velocity, it follows that the cold current of air which sets in from the temperate zones towards the equator not only has a motion north and south in that direction, but also a velocity of about 850 miles an hour due to that parallel of latitude from which it is withdrawn; the equatorial regions, however, are moving to the eastward at the average rate of 980 miles an hour: the cold air arriving into these regions at the slower rate would, on its first arrival there, be left behind; or, in other words, the surface of the earth would travel faster to the eastward than the air upon it, and this would produce an apparent or relative motion in the air from east to west, that is, an easterly wind. Thus the cold current moving towards the equator is influenced by two sources of motion; the first caused by the heat of the torrid zone producing a partial vacuum, to fill up which the cold air from the temperate zones rushes in towards the equator and at right angles to it; the second source of motion is that which has been communicated to it in a direction due east by the rotation of the earth in the temperate latitudes it has left. The resultant of these two motions is the south-east trade-wind in south latitude, and the north-east trade-wind on the northern side of the equator.

When the slower-moving air of the temperate zone first arrives at the quick-moving or tropical belt of the earth, the

difference of their velocities is great compared with the other motion of the cooler air towards the equator, and consequently the wind blows at the extreme edges of the trades, nearly from the east point. This gradual change in the direction of the trade-winds is thus accounted for:—As the difference in velocity between each parallel and the next becomes less and less in approaching the equator, so the lagging behind of the air, which constitutes its westward tendency (or *easting* as it is called by sailors), becomes less and less. The 30th parallel, which moves at the rate of 903 miles an hour, has a less velocity by 77 miles than the 20th parallel, which moves at the rate of 980 miles an hour, while the 20th is only 46 miles an hour slower than the 10th parallel. Thus, the air in travelling from the 30th to the 20th parallel must be more retarded, or have more easting than that which travels from the 20th to the 10th parallel. As the air from the cooler regions draws near the equator, its velocity is checked by becoming heated, which gives it a tendency to rise rather than to flow along the surface; and it is further checked by the meeting of the two opposite currents, one from the north and the other from the south.

As every current towards the equator must be rendered easterly, so every current from the equator must become a westerly wind, because it proceeds from a quick moving into a slower moving latitude, and must therefore rotate quicker than the part of the earth on which it arrives. And as this cause operates least powerfully near the equator, and becomes more powerful in receding therefrom, this would cause the upper tropical current to become more and more westerly as it advances towards the temperate zones; thus describing the same apparent curve as the trade-winds below it, and moving everywhere in a direction exactly opposite to them, —a fact which has been established by observation. When this upper current first precipitates itself on the earth's surface, about the 30th parallel of latitude, it has lost but

little of its equatorial velocity, because the only friction to which it has been subjected is that of the lower current ; and hence the furious westerly gales which are so prevalent beyond the limits of the trade-winds, or about latitude 30°, in each hemisphere.

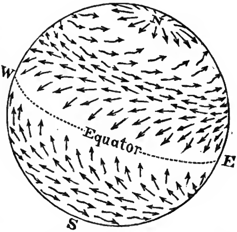
The equatorial limit of the two trades, or the region of calms and light variable winds, is subject to continual change, depending on the position of the sun. As the circle of greatest heat does not coincide with the equator, except at the time of the equinoxes, but with a parallel to the north or south of it, it will readily be seen how the whole system of tropical winds must to a certain extent follow the sun; that is, the limits of all these winds must advance northward in our summer, and recede southward in our winter. Hence the regions of calms and light variables is bisected by the equator only at the equinoxes. In July and August this region is wholly north of the equator, and extends as far as 12° north latitude, while in January it is, on the contrary, almost entirely in the southern hemisphere. Thus, in our summer, the southern trade sometimes crosses the equator, and advances a degree or two to the north of it ; while, in our winter, the northern trade advances nearly up to the equator, but never crosses it. The reason for this difference is the greater average amount of heat in the whole northern compared with the southern hemisphere. Indeed, the line of greatest mean yearly heat is situated entirely within the northern hemisphere, nowhere approaching the equator nearer than three degrees. The phenomena of the winds are, therefore, symmetrical on each side of the line of greatest mean yearly heat rather than on that of the real equator.

The outer or temperate limits of each trade-wind also partake of this northward and southward shifting, because, the warmer either hemisphere may be, the farther will the upper current travel into the temperate zone before it becomes sufficiently cooled to sink and usurp the place of the lower current, which constitutes the trade-wind. Hence

there are places situated about the 28th parallel in each hemisphere which have a constant east trade-wind during their hottest months only, and the above-mentioned westerly gales during the cooler part of the year.

The following figure, Fig. 28, will serve to show the prevailing direction of the winds or *lower* atmospheric currents at different parts of the earth's surface, apart from the effects of local peculiarities, such as sea and land breezes. The facts intended to be impressed on the mind by this diagram are, 1st, the prevalence of *calms* within a few degrees on each side of the equator, varied, however, by frequent short squalls and light variable winds from every point; but, according to Captain Basil Hall, mostly from the south, probably on account of the general lower temperature of the southern hemisphere than the northern. 2ndly. The constancy of the trades from the 10th to the 28th degree of latitude, their directions being *polar* where they approach nearest the equator, and gradually more and more *easterly* in receding therefrom, until outside the tropics they become *east*. 3rdly. The conflict and alternate preponderance of these *east* winds and of *west* gales about the 30th parallels. 4thly. The prevalence of *easterly* and *equatorial westerly* winds from the 30th to the 60th parallels. 5thly. The prevalence of *polar* gales about the arctic and antarctic circles.

Fig. 28.



It is of course impossible in Fig. 28 to show the upper

currents,* which should theoretically blow at every spot, nearly contrary to the prevailing lower ones. Free from all the irregular disturbances of the earth's surface, these upper currents are supposed to flow with a slow but unruffled and undeviating constancy, as seen in the motions of lofty clouds, and confirmed by the experience of aëronauts. Mr. Green states, that in this country, whatever may be the direction of the wind below, within 10,000 feet above the surface of the earth its direction is invariably from some point between the north and west.

42. We must now notice certain modifications in the trade-winds, produced by the presence of large masses of land. If the earth were a uniform mass of water or of land, these winds would blow with the utmost regularity; but as the surface of the earth is broken very irregularly by masses of land and water, the law of the trade-winds is greatly disturbed. This is especially remarkable in Mexico and India. That part of the Pacific which extends from the Isthmus of Panama to the peninsula of California lies between 8° and 22° N. latitude. The sun's rays striking directly on the great territory of Mexico, heat the land strongly, thereby causing the air over it to rise; the vacuum is filled up not only from the northward, but also by the comparatively cool air of the equatorial regions in the neighbourhood. The air coming from that part of the globe which revolves quickest to a part which moves more slowly, produces not an easterly wind, but westerly and south-westerly winds; so that the navigator is often very much embarrassed who expects east or north-east winds, according to the usual theory of the trade-wind.

The monsoons of the Indian Ocean are also modifications of the trade-winds due to the presence of vast masses of land. These winds are called *periodical*, to distinguish them from the trades, which are *constant*. They blow for nearly six months of the year in one direction, and for the other six in

* These will be found represented in Fig. 27.

an opposite direction. The Malays call them *mooseen*, which signifies *season*. These winds blow with the greatest regularity between Hindustan and the eastern coast of Africa. When the sun is south of the equator, from October to April, a north-east monsoon prevails; but when the sun is north of the equator, from April to October, a south-western current is established. When the sun passes the equator, and the monsoons are changing their direction, variable winds or tempests generally occur, a disturbance which is called by seamen the "breaking up of the monsoons."

The theory of the monsoons will be readily understood after the foregoing account of the trades. When the sun has great northern declination, the peninsula of Hindustan, the north of India and China, being strongly heated, the quick-moving air of the equator rushes to the northward, to fill up the slower-moving rarefied space; and this supply of air, having not only a rapid velocity towards the east, but also a motion from the south, produces the south-west monsoon in the Indian Ocean, in the Bay of Bengal, and in the China Sea. When the sun, on the other hand, has great southern declination, the same seas are occupied by air, which, coming from regions beyond the northern tropic, has less easterly velocity than the space it is drawn into. This gives the air an easterly direction, which, combined with its proper motion towards the equator from the north, produces the north-east monsoon.*

* The monsoons are as advantageous to commerce as the trade-winds. It is chiefly by means of the north-east and north-west monsoons that the voyages of merchant ships from Canton to England are accomplished in the comparatively short period of 120 days; the distance traversed being about 14,000 miles, and the progress of the vessel nearly 120 miles a day. The advantages which vessels sailing from Europe to Calcutta, Singapore, and Canton derive from the south-west monsoon are also very great, although their voyages are much longer. The inhabitants of the countries within reach of the monsoons also derive great advantages from them. With one monsoon their vessels leave their country, and with the other they return to it, the interval between the two monsoons being disposed of in selling their cargoes and procuring others for the return voyage.

43. In addition to the grand effects of the trades and the monsoons, the heating action of the sun produces a *diurnal* interchange of air in some parts of the world, in what are called *land and sea breezes.* The ocean is but little affected by sudden changes of temperature, such as are produced by the succession of day and night, and it participates only to a certain extent in the alternating temperatures of the seasons. Such changes become equalized over large tracts of salt water, and serve to temper the rigours of climate on coasts and in islands. The land, on the contrary, becomes rapidly heated by the sun, and as rapidly cooled in his absence. Thus the great continents act as heaters and coolers of the atmosphere, and produce those changes in the aërial currents already noticed; and not only continents, but islands of moderate size, produce the daily alternation of land and sea breezes, so refreshing upon the coasts of hot climates. During the day the land becomes much more heated by the sun than does the adjacent water, and consequently the air resting upon the land is much more heated and rarefied than that upon the water. The cooler and denser air, therefore, flows from the water towards the land, constituting the *sea breeze*, and, displacing the warmer and lighter air over the land, forces it into a higher region, along which it flows in an upper current to seaward. At night a contrary effect takes place. After sunset the land cools much more rapidly than the water, and the air over the shore becoming cooler, and consequently heavier than that over the sea, flows towards it, and forms the *land breeze.**

The phenomena of land and sea breezes may be well

* Advantage is taken of these breezes by coasters, which, drawing less water than larger vessels, can approach the coast within those limits where the sea and land breezes first begin to operate. Thus a ship of war may not be able to take advantage of these winds, while sloops and schooners may be moving along close to the shore under a press of canvass, and be out of sight before the larger vessel is released from the calm bordering these breezes, and fringing for some time the beach only. The old navigator Dampier gives an admirable description of these breezes.

illustrated by a simple experiment. Fill a large dish with cold water, and place in the middle of it a saucer full of warm water; let the dish represent the ocean, and the saucer an island heated by the sun, and rarefying the air above it; blow out a wax taper, and if the air of the room be still, on applying it successively to every side of the saucer, the smoke will be seen moving towards it and rising over it, thus indicating the course of the air from sea to land. On reversing the experiment, by filling the saucer with cold water, and the dish with warm, the land breeze will be shown by holding the smoking wick over the edge of the saucer; the smoke will then be wafted to the warmer air over the dish.

44. In most mountain districts alternating currents may be observed in the atmosphere, which partake of much of the nature and regularity of land and sea breezes; they have been distinguished by the name of *hill and valley breezes*, and as the subject is almost new to science, it may be interesting to give an example of them.*

At Nyons, in the department of La Drôme, a wind has been known from time immemorial, under the name of *Pontias*. It is a cold wind, and rises every evening about 9 or 10 o'clock in summer, and at 6 in winter. Its first approach is from a narrow, deep, winding gorge, about two leagues in length, and extending on one side into the plains of the Rhone, near Nyons, and on the other side into a large valley, inclosed by the mountains of La Drôme. The breeze increases progressively during the night, until sunrise, when it begins to decline in intensity, and finally dies away when the ground has been warmed by the sun. This breeze is much more cold and violent in winter than in summer, and it often produces such a depression of temperature as to congeal the moisture of the atmosphere. In summer it has

* The subject has been raised into the importance which it seems to merit by M. Fournet, in the *Annales de Chimie et de Physique* for 1840.

the effect of a fresh morning breeze. Its regularity is very remarkable, although subject to certain disturbances. Thus, during the greatest heats of summer, when the short nights are not sufficient to cool the surface of the parched ground, the *Pontias* is scarcely perceptible. A similar effect is produced by a rainy or a cloudy night. Snow, on the contrary, appears greatly to favour this breeze. The effect of these variations is limited to its progress. In winter, or immediately before or after rains, it sometimes descends as far as the Rhone, a distance of seven leagues; but in summer, or during serene weather, it extends to a much shorter distance.

This breeze does not exist in the upper regions of the atmosphere, nor even above the hills in the neighbourhood of Nyons, but seems to be entirely confined to the defile, at the entrance to which stands the town. It does not blow in an equal current, but is subject to certain swells at intervals of a few minutes, and these are most distinct when an east wind opposes its exit; it then escapes by irregular puffs. On ascending the defile, which leads into the upper gorge, the force of the wind diminishes in proportion to the ascent, and at length is entirely lost at a certain elevation.

In connection with this breeze is an upper compensating current, called *la Vesine*, or the *bad* wind, which, ascending the river of Eygues, passes over a defile, and is lost in a larger valley. This wind increases in violence with the heat of the day or of the season.

Thus we observe two breezes periodically opposed to each other; the one a nocturnal breeze, and the other a day breeze, blowing in opposite directions, according to the hour of the day, and developed entirely by the physical features of the locality. M. Fournet has also established the existence of hill and valley breezes in other mountain districts of France and Switzerland, caused chiefly by the asperities of the soil, producing daily an atmospheric flux and reflux,

which manifests itself in ascending and descending breezes known in different places by local names.

45. There is, however, a distinction to be attended to in comparing the daily alternations of wind produced by mountains with those produced by coasts. The sea breeze is much more general and decided than the nocturnal or land breeze, whereas, in mountain breezes, the nocturnal or hill breeze seems to be the most regular; because, although the mountain summits receive by day more and stronger sunshine than the lowlands, yet they also reflect and radiate more heat, besides being more cooled by the colder air in contact with them, so that on the whole it is doubtful whether they would generally become warmer than the plains, so as to receive a diurnal breeze from them, except in particular localities. But by night everything conspires to reduce the temperature of the summits, which, from their isolated position, radiate their heat in every direction through the clear rarefied air into boundless space, while the lowlands can only radiate their heat upwards and through a denser and less transparent air; and even that which they do radiate is often reflected back by a canopy of clouds, so that the nocturnal breeze *from* the hills must be far more general than the diurnal one *towards* them. In the case of sea and land breezes, on the contrary, although the land must always be more heated by day than the sea, thus producing the sea breeze, there is no apparent cause why the land, which is a worse radiator of heat than water, should ever become cooler than the water by night, so as to send forth a land breeze, properly so called. The winds so designated appear, therefore, to be truly not *land*, but *hill* breezes. We are not aware that they are ever felt on *flat* shores, such as Demerara, although this is one of the hottest coasts in the world, nor on the flat island of Barbadoes; but they are felt off the neighbouring island of Grenada, which is smaller, but mountainous.

46. Our space will not allow us to notice the interesting

phenomena of the winds at greater length ;* we must, however, just glance at those winds which are produced by whirls or rotatory movements in the atmosphere of greater or less extent, the winds which have hitherto engaged our attention being general or periodical winds of the nature of currents.

Rotatory disturbances in the air display a variety of phenomena which have been distinguished by various names, such as *whirlwind, water-spout, sand-spout, sand-pillar, tornado, white squall, pampero,* &c. These terms have been applied to rotatory storms of small extent. The *hurricanes* of the West Indies and the *typhoons* of the Indian seas are whirls of greatly increased extent, often extending from one to four or five hundred miles in diameter, and consisting of a revolving movement propagated from place to place, not by bodily transfer of the whole mass of air which at any moment constitutes the hurricane from one geographical point to another, but by every part of the atmosphere in its track receiving from that before it and transmitting to that after it this revolving movement.

It was formerly supposed, when accounts of hurricanes were received, as occurring at different islands on various dates, with marked differences also in the direction of the wind, that those violent storms were rectilinear in their course, and that such accounts related in most cases to different storms. Their true nature was first clearly established by Mr. Redfield, of New York, and afterwards by Lieutenant-Colonel Reid, Governor of Barbadoes, by constructing charts on a large scale of some of the most remark-

* The principal phenomena of the winds are brought together in a popular form in a little book by the author of this work, entitled "The Tempest; or, an Account of the Nature, Properties, Dangers, and Uses of Wind in various Parts of the World." Published under the direction of the Committee of General Literatnre and Education, appointed by the Society for Promoting Christian Knowledge. In Weale's "Rudimentary Navigation" will be found an essay by the author of this work, "On the Law of Storms and of Variable Winds, and its Practical Application to Navigation."

able hurricanes on record. In this way a single storm was traced successively from one island or locality to another, and the direction of the wind at any one point or place was found to have no connection with the general progress or direction of the storm. For example, one of the tracks thus laid down is that of the memorable gale of August, 1830, which passing close by the Windward Islands, visited St. Thomas's on the 12th; was near Turk's Island on the 13th; at the Bahamas on the 14th; on the Gulf and coast of Florida on the 15th; along the coast of Georgia and the Carolinas on the 16th; off Virginia, Maryland, New Jersey, and New York on the 17th; off George's Bank and Cape Sable on the 18th; and over the Porpoise and Newfoundland Banks on the 19th of the same month, having occupied about seven days in its ascertained course from near the Windward Islands, a distance of more than 3,000 miles, the rate of its progress being equal to 18 miles an hour. Now, the actual velocity of the wind in its rotatory movement is probably five times greater than this rate of progress, which would be equal in a rectilinear course to about 15,000 miles; but the whole length of the track does not exceed 3,000 miles: we thus have strong evidence of the rotatory nature of these storms; for if the wind move 90 miles an hour, and the whirls or eddies which constitute the storm move in a body at the rate of only 18 miles an hour, it is clear that the motion of the wind must be in circles. It is curious also that these eddies turn in a direction contrary to the sun's apparent daily motion, and, therefore, in our hemisphere, contrary to the motion of the hands of a watch, but similar to that motion in the southern hemisphere, a result which would naturally be expected from their common origin, just as two wheels set in motion by anything passing between them must necessarily turn in contrary directions. The general progress of these storms is always away from the equator, and therefore reversed in the two hemispheres; but in both they have first a westward motion, until they

escape the influence of the easterly trade-winds, when they turn round in a hyperbolic curve and are drifted eastward by the prevailing westerly winds of each temperate zone. Throughout their course they increase in size, but diminish in intensity, until they are lost in the winds of high latitudes, the variable and fluctuating nature of which they greatly increase.

Sir John Herschel explains the origin of one of these rotatory storms, by supposing a column of air, intensely heated at a particular point of the intertropical plains of America, to rise bodily from the lower stratum of the atmosphere with sufficient ascensional force to carry it into the upper current, but retaining the full westerly energy which it has derived from the earth's rotation. Now nothing is more likely than that a *ripple* in its course should thus be produced, and that the portion thus driven upwards should, on its return, strike down far below, into the lower current. All the conditions necessary for a rotatory storm would then arise. A mass of air, animated with immense velocity, has to force its way through an atmosphere either at rest or moving in a contrary direction: a state of things which, in the movements of fluids, is invariably accompanied with vortices on one or both sides of the moving mass, which continue to subsist and to wander over great tracks long after the original impulse is withdrawn. In such vortices the motions of translation and rotation may have any proportion; but the former is usually slow compared with the latter. An illustration of this kind may be witnessed at a mill-dam when the sluice is closed so as to allow the water to escape at some small hole. A funnel-shaped depression will appear on the surface, in which air descends, often to the actual hole of escape, though many feet below the surface, but often also as an interrupted column. All the movements of a rotatory storm are here represented by the revolving fluid. So long as the hole is kept open, it retains a fixed position, at least at the lower extremity, fluctuating

only by a bend of the column. But if the hole be closed, it immediately begins to wander, continuing often a long time, but gradually retreating upwards.

47. It must be obvious that all these atmospheric currents, depending as they do entirely on the variations of elasticity brought about in different parts of the atmosphere by the solar heat, must be most intimately connected with the indications of the barometer. As the tendency of all these currents is to establish equality of pressure over the earth's surface, it was formerly supposed that the *mean* height of the barometric column would be found equal in every part of the world. Numerous careful and long-continued registers of its height, however, kept at various spots distant from each other, have shown a decided though very small local variation of this element, and the dependence of this variation on the latitude we will now endeavour to explain.

The atmospheric pressure is greatest at, or at a short distance beyond, the tropics, or about the outer limit of the trade-winds, where the mean height of the barometer is about 30 inches. From this point it declines both towards the equator, where it is about 29·9, and also towards high latitudes. In England, for example, it is reduced to 29·8, and it continues to fall at about the same rate to the highest latitudes that have been reached. But towards the South Pole, as appears from the expedition under Sir J. C. Ross, the fall appears to increase rapidly, so much so, that in the Antarctic regions the mean pressure is reduced even below 29 inches; but it must be remembered that this is only the mean of three *summers*, and may possibly be compensated by increased pressure in *winter*.

The maximum of mean pressure occurring just outside the tropics, is referred by Professor Daniell, with great probability, to the obstruction caused by the meeting and crossing of the two main currents as already described (41), which must produce an accumulation of air upon that parallel where it occurs.

But the mean local pressure appears to depend less on latitude than on the proximity of great masses of land or water, it being highest in the interior of continents and lowest on the Pacific. Captain King, in a voyage on that hemisphere of waters, having observed the barometer five times a day for five months, obtained a mean of only 29·462 inches. Connected with this fact is the lower mean pressure in the Antarctic regions than in the Arctic, and also the well-known fact of the barometer on the borders of continents (as in this country) standing lowest during moist winds, or those which come from the ocean, and highest during the dry winds from the continent.

48. This brings us to the fact, that the local differences between the mean pressure observed at the most distant parts of the globe are very trifling compared with the variations constantly occurring at most places, indeed all places, outside the tropics. Thus in this country we have at the sea-level the mercury not unfrequently rising to 30·5 inches, and sometimes falling to 28·5. This difference of two inches indicates a difference of about a pound per square inch in the atmospheric pressure, so that we need not wonder that delicate persons feel the change, when the pressure on their body is increased or diminished in this manner by a few hundredweights.

These fluctuations in the barometer are by no means of equal extent in different places. Their amount increases greatly with the latitude, being much greater at St. Petersburgh or Stockholm than in London, while in warm latitudes it is greatly diminished, and within the tropics becomes not only so small as to escape the notice of unscientific persons, but assumes a totally different character from that which it has in cold and temperate climates. This difference we will proceed to explain.

49. The fluctuations occurring in extra-tropical latitudes are so fitful as utterly to defy all attempts to reduce them to rule, that is, to any periodical order. Indeed, this must be

obvious from their generally acknowledged connection with the wind and weather, the uncertainty of which is proverbial. But in the torrid zone, where this uncertainty, as regards two elements at least, namely *wind* and *temperature*, is replaced by the most clock-like regularity, the barometric changes, although so small as to be scarcely perceptible to an indifferent observer, partake of the same perfect regularity. Unaffected by the utmost extremes of wet or dry, it gives no indications of the approach of the equinoctial deluges, or the solstitial drought; it is thrown aside by the planter as a useless instrument, nevertheless its small daily oscillations go on with the regularity of a clock. Scarcely once in a man's life, at any one spot, does the mercury undergo a decided disturbance, and that not greater than occurs in England before a slight thunder-shower, but such a disturbance is the sure and rapid precursor of one of these stupendous atmospheric convulsions, which, in the extent of their disastrous effects, are scarcely exceeded by the greatest earthquakes. The importance of observing the barometer at sea, within the tropics, cannot be overrated. There are many instances recorded of ships saved from otherwise certain wreck, by the rapid fall of the mercury giving notice of an approaching hurricane.

But to return to the ordinary oscillations; it is found that, totally unconnected with changes of weather, these oscillations occur like the tides of the ocean, twice in every twenty-four hours, only with this difference, that they are purely *solar* tides, or those arising from the action of the sun only, not *soli-lunar*, or those arising from the combined action of the sun and moon. They have no variations of *spring* and *neap*; and instead of their rise and fall occupying half a *lunar* day,* it occupies only twelve hours, or half an ordinary solar day, the two maxima of pressure always occurring at the same hours, namely, at 9 o'clock A.M. or P.M., and the two

* The mean length of the lunar day is $24^h\ 50'\ 21''$.

minima each at about 3 o'clock A.M. or P.M. This is, therefore, a tide not produced by gravitation; for if it were, the sun's effect would, as in the oceanic tides, be masked by the greater effect of the moon; but being dependent solely on the sun's position, this atmospheric tide must be due not to his attraction, but to his heat. The manner in which this power acts so as to produce *two* opposite and equal protuberances of the atmosphere, is beset with difficulties, and cannot yet be said to be even partially understood; but the facts are nevertheless of the greatest interest to science.

50. In speaking of the *semi-diurnal* oscillations, we must always be understood to refer to what takes place at the level of the sea, because on an eminence their effect is necessarily partly disguised by the super-addition of that *diurnal* oscillation deduced above, the period of which being 24 hours, it must have the effect of making these 12-hour tides appear alternately unequal; and this inequality is greater the higher we ascend.

The extent of the semi-diurnal oscillation is found to be greatest at the equator, where it averages more than $\frac{1}{10}$th of an inch, and it diminishes to $\frac{6}{100}$ths of an inch in lat. 30°; being, however, in both situations greater in the hottest months than in the coolest. Beyond the limits of the trade-winds, these oscillations being still further diminished, are exceeded in extent (and therefore entirely masked) by the *irregular* fluctuations so familiar in our climate. These fitful variations, unknown within the tropics, increase prodigiously in extent as we recede therefrom; and as the *regular* oscillations, on the contrary, diminish, they are of course soon lost in, or confounded with, these *irregular* ones.

51. But although thus disguised so as to be no longer recognisable by simple observation, this regular tide still flows and ebbs amidst all the irregularities of the pressure in temperate climates. The proof of this is simple and elegant.

We have only to examine a barometric register kept at stated hours (at least twice a day) for a long period, to take the average of each set of observations made at the *same hour*, and by comparing these averages, it is found that the mean height at about 9 o'clock A.M. is greater, and that at about 3 o'clock P.M. less than at any other hour. In this climate, and in summer, the mean of a few weeks is sufficient to elicit this fact. In winter, or in higher latitudes, the greater extent of the irregular fluctuations requires a longer series to enable them to neutralize each other. In this way it is found that, however disguised by irregular disturbances, the regular atmospheric tide still obtains throughout the temperate zones, although greatly diminishing in extent from the tropics to the Polar circles, near which it becomes altogether imperceptible. Among the many theories proposed to account for these oscillations, that of Professor Daniell is the most satisfactory. It is too complex to be introduced here, but we may observe that he deduced from it not only the entire disappearance of these tides at a certain latitude far short of the Pole, as above stated, but also that in higher latitudes a much smaller tide ought to appear at exactly the contrary hours, that is, flowing from 9 to 3, and ebbing from 3 to 9; and an examination of the register kept for this purpose in Captain Parry's Second Arctic Expedition, has actually given such a result, although its amount is so very small, only a thousandth of an inch, that considering the great extent of the irregular fluctuations, it is very doubtful whether the observations were continued long enough to give a fair average.

52. This principle of obtaining the mean of many observations made under circumstances bearing a certain resemblance, and comparing this mean with the mean of many others made without that particular resemblance, is the keystone of the meteorological arch, the sole method of accumulating that mass of material by which the infant science of meteorology is to be nourished. It is only by such averages

that the diurnal tide, observable only on eminences (50), can be shown to exist. Professor Daniell elicited it from the mean of a very moderate number of observations, even on so small an elevation as Box-hill, in Surrey, and the registers kept at greater heights show it distinctly, provided they be on narrow summits or ridges; on extensive table-lands it is not observable, because the air resting on them has not time to flow off during the night, nor the surrounding air to overflow them during the day. This alternate flux and reflux, however, produces at the border of all elevated tracts the hill and valley breezes already noticed (45), namely, a breeze *from* the hills during the night, and *towards* them during the day, similar in character to the land and sea breezes, and like them most observable in low latitudes, because the daily and nightly alternations of temperature are there greatest.

53. The observations on Box-hill just noticed, also displayed another oscillation, which, from the time of Newton, had often been sought for in vain, namely, the atmospheric *tides*, strictly so called, produced by lunar attraction. It is obvious that such tides, however great, could never affect the height of the barometer at the sea-level, because the greater height of air accumulated under the moon would, on the whole, weigh no more than the shorter column elsewhere, because every particle of the former column (and also of the mercury weighing it) has its weight diminished by the moon's attraction opposing that of the earth. But the effect ought to be seen by the upward diminution of pressure being *slower* under the moon; and, accordingly, the mean of several observations made when the moon was near the meridian, gave a less difference between the pressures at the foot and top of the hill than was obtained from the mean of several others made when the moon was near the horizon. It is to be regretted that similar observations have not been made at greater elevations, as they have an important bearing on the use of the barometer for measuring heights.

This subject will be noticed presently (56), but we must first make a few remarks on the use of the barometer as a *weather-glass.*

54. This instrument could not have been long observed before the discovery that its fluctuations had some unknown connections with the changes of the weather in temperate climates, especially as regards wind and rain; a high state of the mercurial column generally occurring in the finest or calmest weather, and a depression of it during rain and storms. Hence, by a too hasty generalization, it was supposed that the fineness of the weather was exactly proportional to the atmospheric pressure, and, accordingly, such words as "fair," "changeable," "rain," &c., were engraved on the scale, which words have only served the purpose of bringing a really invaluable instrument into disrepute, by making it promise that which it is incapable of foretelling.

The reason why the atmospheric pressure is generally greater in dry situations, and in dry states of the weather than in moist ones, is still very obscurely known. We cannot even touch upon it in this place, because its consideration would require on the part of the reader a knowledge of the laws respecting vapour, and we prefer that he should gain from this little book a tolerably complete knowledge of the barometer, than an imperfect idea of the barometer and the hygrometer; but we may observe that a due attention to both these instruments will lead to more accurate predictions respecting the weather than can be obtained by the use of either of them singly. Indeed, the barometer used alone has, as we have endeavoured to show, a far more direct application to the theory of winds than to that of rain.* Its

* Mr. Belville appears to coincide with this view, and accordingly has given a set of rules, connecting the phenomena of the barometer with the direction of the wind, and also with the appearance of the clouds, according to Howard's nomenclature. Mr. Belville also gives a table showing the mean height of the barometer at noon for Greenwich, for every day in the year, deduced from thirty consecutive years' observations, viz. from 1815

application to the latter is only indirect, and far from being understood theoretically; still, however, the average of a large number of observations made at different times, and in different places, has furnished rules which deserve some degree of reliance.

The most important fact to be remembered is, that the state of the weather to be expected is not so much connected with the absolute height of the column as with its *motion*, whether *rising* or *falling*. In order to observe this most important fact an upright barometer is necessary, since the upper surface of the mercury cannot be seen in a wheel barometer. If the mercury have a convex surface the column is rising; if it is concave it is falling; when it is flat it is generally changing from one of these states into the other (33).

A fall in the mercury generally indicates approaching rain, high winds, or a thunder-storm; but it is remarkable that snow is more frequently preceded by a rise than by a fall. With this exception, however, a rising state of the mercury commonly indicates the approach of fine weather. A very high wind, especially from the S.W., whether accompanied by rain or not, is perhaps connected with the lowest

to 1844, and reduced to 32° Fahr. The following are the monthly means from this table:—

	Inches.
January	29·909 second maximum.
February............	29·859
March..............	29·857 second minimum.
April	29·865
May	29·884
June	29·910 maximum.
July	29·894
August	29·890
September	29·872
October	29·851
November	29·801 minimum.
December	29·884

The mean annual pressure for noon at Greenwich is 29·872 inches.

state of the barometer.* In England a N.E. wind is more conducive to a high state of the mercury than any other.

When the mercury rises or falls steadily for two or three days together, it is generally found that rather a long continuance of settled weather will follow; rainy in the latter case, and fine and dry in the former. By the same rule frequent fluctuations in the height of the column are found to coincide with unsettled weather.

55. Many persons are fond of entering the height of their barometers in a register once or twice a day for years together, and make no further use of these registers than to exhibit them to their friends as curiosities, and point out a remarkably low state of the barometer at one period, and contrast this with a remarkably high state at another period. It may be thought a harsh word, but it is a fact that, as far as science is concerned, these registers are no better than waste paper; whereas they might be made of inestimable value by taking out the *monthly* and *annual means*, and sending them for publication to some local newspaper, or to any scientific journal of repute. Persons who have a tolerably good instrument, and the leisure and inclination for these observations, should make their entries at the proper hours of the day, and these are indicated by the instrument itself (49, 51). The maximum height of the column is about 9 o'clock A.M., the mean at 12, and the minimum at 3 P.M. If a person can afford time to make three observations every day, he should select these hours. If he can only make two observations, the proper periods are the very convenient hours of 9 A.M. and 9 P.M. If he can make only one observation, *noon* is the time. Professor Daniell remarks, that those who merely consult the barometer as a weather-glass would find it an advantage to attend to the three above-

* Mr. Belville states that the lowest depressions of the barometer occur with the wind at S. and S.E., when much rain falls, and frequently short and severe gales blow from these points.

mentioned periods, for he has noticed that by much the safest prognostications for this instrument may be formed from observing when the mercury is inclined to move contrary to its periodical course. If the column rise between 9 A.M. and 3 P.M., it indicates fine weather; if it fall from 3 to 9, rain may be expected.

56. The *measurement of heights* was the first useful purpose to which the barometer was proposed to be applied, preceding even its application as a weather-glass; and in this respect it is certainly more to be depended on than any predictions as to the weather made from it, even for only a few hours in advance. This application was suggested by the results of experiments performed by Torricelli and Pascal, that the mercurial column diminished in height on ascending above the level of the sea. But, at the outset of this inquiry, Pascal fell into a great error by supposing the atmosphere to be of equal density throughout, and that as the whole atmospheric column supported about 30 inches of mercury, all that was necessary was to observe the depression of the mercury on ascending a mountain, and then, by comparing the relative weights of mercury and air,* to ascertain the height of the mountain. The error, however, was soon discovered. Halley showed that the density of air decreases in a geometrical progression, while the elevation increases in an arithmetical progression; that is, if at a certain height the density was half that at the earth's surface, it would be *one-fourth* at twice that height; *one-eighth* at thrice that height, and so on; and Mariotte, about the same time, having determined that the pressure of aërial fluids is exactly proportional to their density when the temperature is equal (9), it was clearly proved by Halley that the ratio of decrease in the pressure was different from that of the increase in the heights. Indeed, if the upward diminution of the temperature be equal for equal ascents (39), it may be shown, for heights which are in arithmetical progression,

* This has been determined by Biot and Arago to be 10,466 to 1.

that the elasticity diminishes in geometrical progression like the density, but rather more rapidly.

Now, the relation between an arithmetical and a geometrical progression is the same as that between a series of logarithms and their natural numbers; and it occurred to Halley to apply a common table of logarithms to the solution of these questions. It was necessary, however, to fix the unit of his two series, which he did by calculating that the height at which the atmospheric pressure is exactly half that at the earth's surface must be about $3\frac{1}{2}$ miles. That is to say, although the atmosphere may extend to the height of 45 miles, yet its *lower half* is so compressed as to occupy only $3\frac{1}{2}$ miles, so greatly do the upper portions expand when relieved from pressure.

Hence at the height of	$3\frac{1}{2}$ miles,	7 miles,	$10\frac{1}{2}$ miles,	14 miles,	&c.
the elasticity of the atmosphere is	$\frac{1}{2}$,	$\frac{1}{4}$th,	$\frac{1}{8}$th,	$\frac{1}{16}$th,	&c.

Halley was induced, by certain mathematical considerations, to fix upon the number 62,170 as a constant multiplier, and the rule for the measurement of heights may be stated as follows:—Observe the height of the barometer at the earth's surface, and then at the top of the mountain, or other elevated station; take the logarithms of those numbers, and subtract the smaller from the greater; multiply the difference by 62,170, and the result is the height in English feet. This process gives a very near approximation, especially in temperate climates.

But the progress of science soon rendered it evident that a correction for temperature was necessary in barometrical measurements, and a formula has been contrived to meet most of the difficulties of the question. The following rule will be found of easy application:—Multiply the difference of the logarithms of the two heights by the barometer, by 63,946; the result is the elevation in English feet. Then, in order to correct for temperature, take the mean of the

temperature at the two elevations; if that be 69·68° Fahr., no correction is necessary; if above that quantity, add $\frac{1}{480}$th to the whole height found for each degree above 69·68°; if below, subtract the same quantity. For example: Humboldt found that at the level of the sea, near the foot of Chimborazo, the barometer stood at exactly 30 inches, while at the summit of the mountain it was only 14·85. The logarithm of 30 is 1·4771213, and the logarithm of 14·85 is 1·1717237; then subtracting

$$\begin{array}{r} 1{\cdot}4771213 \\ 1{\cdot}1717237 \\ \hline 0{\cdot}3053976 \end{array}$$

Multiply this by 63,946, which produces 19,539 for the elevation in feet. If the mean temperature of the two stations were 69·68°, no correction is necessary for temperature. This is a tolerably close approximation: the most careful calculation has given 19,332 for the real height, and this was probably estimated for a lower temperature.

A method has been given by Leslie for measuring heights without the use of logarithms. His rule is as follows:—Note the exact barometric pressure at the base and at the summit of the elevation, and then make the following proportion:—As the sum of the two pressures is to their difference, so is the constant number 52,000 feet to the answer required in feet. Suppose for example the two pressures were 29·48 and 26·36; then

As 29·48 + 26·36 : 29·48 — 26·36 : : 52,000 feet : 2,905·4 feet, the answer required.

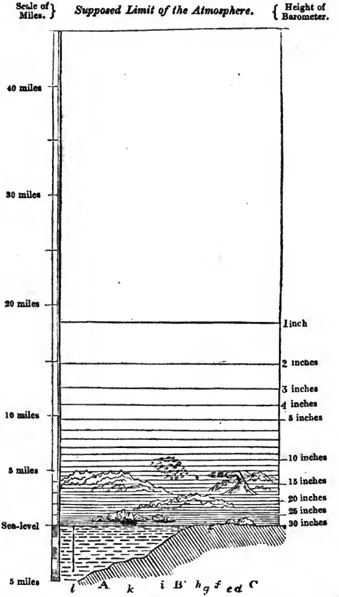
This rule has been found applicable to the mean temperature of our climate for all heights under 5,000 feet, and is therefore available for all the elevations in Britain. The barometer should be furnished with a vernier for reading off hundredths of an inch (24), as a difference of $\frac{1}{10}$th of an inch will indicate from 88 to 100 or 110 feet, according to the

density or pressure. Of course the results are not perfectly but only approximatively true.

57. Fig. 29 contains a scale of the most remarkable heights and depths, compared with the probable height of the atmosphere. The horizontal lines show the heights to which a barometer must be carried to make the mercury sink to the number of inches indicated in the right-hand column. Thus, supposing the pressure at the sea-level to be equivalent to 30 inches of mercury, at the height of two miles (as shown on the left-hand scale) the pressure will be reduced to about 20 inches (as seen by the right-hand scale), showing that at this height the barometer is relieved of $\frac{1}{3}$rd of the ordinary pressure, or, in other words, that $\frac{1}{3}$rd of the whole mass of air is situated below this level. It will be seen also that at five miles (which is about the height of the highest peaks of the Andes and Himalaya) the pressure is only equivalent to 11 inches; and at $5\frac{1}{2}$ miles to about 10 inches; so that only $\frac{1}{3}$rd of the atmosphere (as regards quantity) is situated above that level. The lines marked 10 and 20 inches, therefore, divide the whole atmosphere into three layers, containing equal quantities of air; and, by the same reasoning, it will appear that all the horizontal lines in the figure divide it into 30 layers of equal mass, so that their extreme inequality of space will give a correct idea of the enormous compression of the lower strata by the weight of the upper; the upper 30th part, for instance, occupying more space than all the remaining $\frac{29}{30}$ths. The plane which divides the atmosphere into two equal halves (or which is marked 15 inches in our figure) will be observed to be at the height of about $3\frac{1}{2}$ miles, or 18,000 feet. Humboldt and Bonpland ascended on the side of Chimborazo a little above this level; and in balloons the barometer has sunk sometimes to 12 inches, showing that the aëronants had risen above $\frac{3}{5}$ths of the atmosphere.

By applying a pair of compasses to the right-hand scale, it will be found that the distance from the 30 to the 15 inch

Fig. 29.



		Feet.
A.	Himalaya	28,000
B	Alps (Mont Blanc)	15,650
C.	Andes (Sorata)	25,250
d.	Ben Nevis	4,350
e.	Snowdon	3,557
f.	Humboldt and Bonpland on Chimborazo	18,576
g.	Dalkeith Mine, Cornwall	1,440
h.	Gay Lussac's Balloon Ascent, in 1804	23,000
i.	Cirri, or Mare's Tail Clouds	20,000 to 30,000
k.	Rain Clouds	1,000 to 7,000
l.	Deepest Sounding by Ross, in the Third Antarctic Voyage	27,600

level is the same as from the 20 to the 10 inch, from the 10 to the 5, from the 2 to the 1, from the 4 to the 2, or from any other number to its half or double. So also the distance between any number and its triple is the same as between any other number and its triple; and the same is true of any other multiple: the distance between 30 and 6, for instance, is equal to that between 20 and 4, between 15 and 3, or 5 and 1. Now, this is the property of a *logarithmic scale* (such as that engraved on the carpenter's sliding rule), viz., that numbers having equal ratios are found at equal distances apart; just as in a table of logarithms, any pairs of natural numbers that have equal *ratios* are found opposite to pairs of logarithms that have equal *differences*, so that numbers in geometrical progression have their logarithms in arithmetical progression.

This law, then, that the elasticity of the air diminishes upwards in a geometrical progression, for heights that increase in arithmetical progression; or that the pressures at different heights vary as the numbers of which those heights are the logarithms, is the foundation of the method of measuring heights by the barometer. This law, although preserved at the greatest accessible heights, cannot remain true throughout the atmosphere, because in such case it could have no limit, for there would be no height at which the pressure could be reduced absolutely to 0, so that air in an inconceivably rarefied state would extend even to the moon and the planets, which is certainly not the case; and indeed various reasons lead to the conclusion that it ceases altogether under the height of 100, and, in all probability, under 50 miles.* Even at 20 miles, it must be rarer than the

* Calculations founded on the duration and appearances of *twilight* (a phenomenon due entirely to the atmosphere) give for its height values varying from 45 to 90 miles. No certain conclusion can, therefore, be drawn from these; but by a different calculation, depending on a more careful collation of the observations made on the Andes and in balloons respecting the upward decrease of temperature and pressure, M. Biot has been led to infer that the elasticity and density become 0 at a height not

vacuum produced by the best air-pump, and at 5 miles probably too thin to support animal life.

58. In addition to the aërial currents of varying degrees of intensity, which constitute all the varieties of wind, there are other movements carried on conjointly with the former, not less important to us, and even more wonderful. These are the vibratory motions by which sound is propagated; and there is something very astonishing in the precision and distinctive character of these aërial pulses. Amidst the multiplicity of sounds which fill the air, there is no difficulty in naming the source of each. The ringing of bells, the hum of insects, the song of birds, the lowing of cattle, the rattle of cart-wheels, the roar of the cataract, and the rolling of thunder; all these and a thousand other sounds are, as it were, daguerreotyped in the air, and represent to us their source with characteristic distinctness. They do not confuse or bewilder us, for although apparently mingled together, we can separate them and attend to any one; we can lay that down and attend to another; and what is perhaps of far greater consequence, we can recognize our friends and acquaintances by the sounds of their voices alone, for no two friends have the same voice, any more than the same countenance. And then how wonderful is the power we possess of shaping air into words, by which we express our thoughts, our wants, our instructions, our promises, our affections to others, by which we regulate the actions and influence the judgment of others. All this is very wonderful, and science can take us a very little way indeed in explaining the *timbre* or characteristic qualities of different sounds. We have also no means of measuring the different intensities of sounds. We have numerous instruments for measuring the effects of heat, electricity, atmospheric pressure and vapour;

exceeding 30 miles. Other philosophers calculate the height at from 40 to 50 miles. The phenomena of twilight may also be accounted for without supposing so great a height as 45 miles; which is therefore more probably above than below the truth.

but we have no *Sonometer* for measuring the intensity of sound, because we do not know what effect of sound can be taken as the true measure of its intensity. A similar objection applies to *Photometers*, or *light-measurers*.

The conditions necessary to the production and propagation of sound were noticed in a former treatise.* A body in a state of stable equilibrium is disturbed therefrom by a certain impulse. It should here be remarked, that mechanicians distinguish two kinds of equilibrium, *stable* and *unstable*.† Both alike are produced by the marked neutralization of different forces, but with this difference—that if a body in unstable equilibrium be moved ever so little, so as to leave a portion of force unbalanced, this force will urge the body further and further from its original position, and it will not rest until it has found a new position of equilibrium. But a body in stable equilibrium not only tends to preserve its position unaltered, but to return thereto when disturbed within certain limits, because the force thus brought into activity does not tend to drive it farther, but to bring it back to its former position. But the momentum thus acquired will not allow it to stop here. It will (if we disregard all loss of momentum by its transference to other bodies) proceed as far beyond the position of equilibrium as it was disturbed therefrom at first, and will thus continue to *vibrate* or oscillate through an equal space on each side of the position of equilibrium. And it would do so for ever, were it not for the action of what are called *retarding forces* or *resistances*, such as *friction*, *resistance of the air*, &c.; or, in other words, the motion is shared among gradually increasing quantities of matter until its intensity becomes inappreciably small.

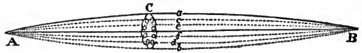
59. The vibrations or oscillations thus produced are usually communicated to the surrounding air, which communicates corresponding vibrations to the ear, which recog-

* Introduction to Natural Philosophy, secs. 15, 43, 44.

† See Rudimentary Mechanics, secs. 16 to 21.

nizes them as sound, provided they be very rapid. The modes of vibration are very different in different bodies. We have already seen how a bell vibrates;* let us now inquire into the modes of vibration of a string stretched tightly between two fixed points, A, B, Fig. 30. On drawing the string aside with the finger, as in the guitar and harp, or with a bow, as in the violin, or with a hammer, as

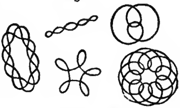
Fig. 30.



in the piano, the force employed converts the right line A B into a curved one, A *a* B. Now, it is obvious that the line A *a* B is longer than A B, and the string, in order to occupy the longer path, must have its fibres or particles separated or strained somewhat further apart. The moment the disturbing force ceases to act, the string, by its elasticity, recovers its position A B, but the momentum it has acquired carries it almost as far on the other side of A B as the original displacement, namely, to A *b* B. The friction of the air and the fixed points A B diminish the momentum of the string, so that on the rebound it reaches only to A *c* B, thence to A *d* B, the oscillations still go on, diminishing to A *e* B, to A *f* B, and, finally, to a state of rest.

The motion of any one point in this string is seldom merely backwards and forwards in a straight line, or even in an ellipse, but more frequently it describes such curves as that shown at C, Fig. 30, or those in Fig. 31, indicating actions of extreme complexity, arising from the various unknown molecular forces of the solid.

Fig. 31.



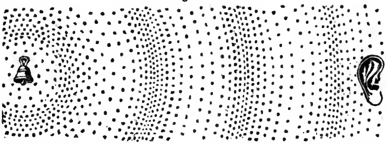
* Introduction to the Study of Natural Philosophy, sec. 15.

60. Now, it must be remarked, that whether these vibrations be large or small they are performed in equal times, because the farther the string is removed from the position of rest the greater is the elastic tension, and consequently the greater the momentum and velocity with which it returns to its original position; and these two elements, the extent of the displacement and the rapidity of the return, are found to increase in exactly the same ratio, a law which applies also to the oscillation of the pendulum.

Every passage of the string over the line of rest A B, Fig. 30, is called a *vibration*, and the mode of comparing two or more velocities of vibration is to choose some small unit of time, such as a second, and to calculate the number of vibrations which occur in such unit.

61. During every vibration of a sounding body the air participates in its motions, and conveys to the ear a wave of sound. We have endeavoured to represent in Fig. 32 what

Fig. 32.



takes place in the air during the ringing of a bell. Every vibration of the bell sends forth a circular wave which spreads in every direction. Now, as these vibrations are *isochronous*, or equal-timed, all the concentric circles are equidistant, like those which proceed from the place where a stone has been dropped into water. Such waves spreading through the air, and therefore breaking upon the ear at *equal* intervals, constitute a *musical note*. In a *noise*, or unmusical sound, the waves follow each other like those of the

sea, with no regularity either in their intervals or their intensities. The more regular they may be, the more clear or musical is the sound. The waves of sound are of course not circles but spheres, not spreading in one plane only, but upwards, downwards, and on every side.

It is further necessary, to constitute a musical note, that the waves succeed each other at least sixteen times in a second, otherwise they will be each heard separately, constituting a *rattle*. But when they are just too rapid to be distinguished separately, they form a very *low* musical note; and the more rapid the higher will be the note. A shrill whistle is due to several thousand vibrations in a second.

62. Now, let us suppose the number of vibrations of a certain string to be 100 in a second. On shortening the string we increase the number of vibrations per second in the very same ratio (inversely); so that it will, if shortened exactly one-half, have its vibrations exactly doubled: it will vibrate 200 times in a second, and this will yield a note exactly an *octave* higher than the former one.*

63. But if, instead of varying the length of the string, we vary the *tension* or force with which it is stretched, we get different results, for the rapidity of vibration is found to be increased as the square root of the tension. Let the string be arranged as in Fig. 33, where one end is fixed securely by a peg; the string then passes over a wedge *a*, and a pulley *b*, and is stretched by a weight, the effective vibrating length of the string being that situated between the two points of support. Let us suppose the string to vibrate 100 times in a second. Now, in order to make the

Fig. 33.

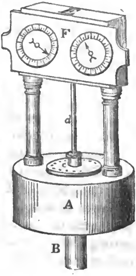
* By doubling the thickness of a cylindrical string, we obtain four times the bulk or mass, and we get the number of vibrations doubled in the same space of time. In order, therefore, to study the effect of length only, we must have strings of the same thickness.

vibrations *twice* as rapid, we must increase the weight *four* times: to make them *three* times more rapid, the weight must be increased the square of three, or *nine* times, and so on. The same arrangement will also prove the fundamental fact, that below a certain rapidity of vibration no sound is produced. If the stretching weight be very small, the vibrations will be sufficiently slow for the eye to follow them, and if the number be less than 16 in a second no sound will be heard.

64. The reader may be surprised at the number of vibrations made by these strings in a second, and may wish to know by what means these high numbers are ascertained. We will endeavour to inform him; but first it is necessary to remark, that the same note produced on any musical instrument is due to the same number of vibrations per second. Thus the tenor C, which is produced by a string vibrating 256 times in a second, as in a piano, is also produced in the flute by a column of air vibrating the same number of times per second, and also in the human voice by two chords (called the *chordæ vocales*) contained in the upper part of the windpipe, also vibrating the same number of times per second. And however different the quality of these notes, as given by different instruments, may be, they all agree in *pitch*, and this is determined by rapidity of vibration.

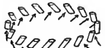
65. There are various methods of determining the number of vibrations per second required for the production of any note. An ingenious little instrument, called the *Syren*, has been invented for this purpose. It is represented in Fig. 34, in which A is a cylindrical chamber of brass. In the instrument used by the writer, this chamber is 3 inches in diameter, and $1\frac{3}{8}$ inch high. A pipe B, $3\frac{1}{2}$ inches long, screws into an orifice in the lower part of this chamber, and fits the tube of a double pair of bellows, or other machine capable of supplying an equable blast of air. The upper surface of the air-chamber, which is called the *table*, is

Fig. 34.



pierced with 25 equidistant holes arranged in a circle. A disc *c*, about $1\frac{1}{2}$ inch in diameter, containing the same number of holes as in the table, and coinciding with them, is supported by a vertical axis *d*, having one bearing below the top of the chamber A, and the other in the box E. The disc *c* is so placed as just to turn freely without touching the table, and the holes through it are bored in a sloping direction, as shown in Fig. 35, while those in the fixed table slope the contrary way, so as to deliver the wind in the directions shown by the arrows, and thus turn the disc after the manner of a smoke-jack.

Fig. 35.



The vertical axis *d* is furnished at its upper extremity, where it enters the box E, with a perpetual screw, which gives motion to a wheel furnished with 100 teeth, and its axle bears one of the hands of the dial shown in front of the box. A single cog on this axle also acts on another wheel of 40 teeth, turning the other index, which accordingly moves over one of the 40 divisions of its dial for every complete revolution of the former index, which revolution corresponds to 100 revolutions of the disc *c*. Now, it is obvious, that during each turn of this disc, the currents of air through it are cut off and reopened 25 times. The circle of holes, both in the disc and in the fixed table, being equidistant, they are all opened and all closed simultaneously, like the apertures of a revolving ventilator; and the hands and dials afford an exact register of the number of these openings and shuttings up to $25 \times 100 \times 40 = 100{,}000$. The wheels are fixed to the front plate only of the box E, and this

plate can be shifted through a small space sidewise, so as to throw the wheels out of gear in a moment.

When this instrument is placed in connection with a double bellows, the stream of air enters the chamber, where it undergoes a slight condensation: it escapes rapidly through the holes in the table, forming a series of oblique jets which set the disc in motion with a rapidity depending on the strength of these currents; and as the air is strongly propelled when the apertures of the table and of the disc coincide, and is suddenly arrested between each coincidence, it follows that each of these alternations agitates the surrounding atmosphere, so that each revolution of the disc produces 25 waves of sound. These waves originate simultaneously from each of the 25 holes; for if either the fixed or the moving plate had only *one* hole (the other having 25), it is evident that the blast would flow and be arrested the same number of times, and would therefore produce the same *note*, but with less intensity. The use of having 25 holes in each plate is simply to strengthen the note without changing its pitch, on the same principle that the three strings given to each note of a grand pianoforte, without making the pitch of the notes differ from that of a single-stringed harpsichord, improve the power and quality. By regulating the force of the blast, and consequently the speed of rotation of the disc, sounds may be produced from the gravest to the most acute. Let us suppose that, by means of this instrument, we wish to ascertain the number of vibrations necessary to the production of a note yielded by an organ-pipe. For this purpose the pipe is screwed into the upper table of the bellows which supplies air to the syren. The action of the bellows will cause this pipe to sound, and its pitch, as will be explained presently, will not be altered whether the blast be moderate or strong. In the syren, however, the disc will rotate slowly or rapidly in proportion to the strength of the blast, and the resulting note is acute in proportion to the rapidity of rotation. It will be easy to regulate the blast so as to make the

syren yield a note strictly unisonant with that of the organ-pipe; and we know that notes in unison of the same pitch are due to the same number of waves or vibrations per second. Now, as the dial-plates of the syren indicate the number of waves generated during the time the wheels are kept in gear, it is obvious that this number, divided by the number of seconds during which they were so kept, will give the number of vibrations per second for the note under consideration. A pendulum beating seconds must therefore be at hand.

A moderate degree of practice in the use of this instrument will enable the observer to determine the absolute number of vibrations per second necessary to the production of any given note without a greater error than one vibration in five seconds. Such observation may be prolonged during several minutes, and thus any small error arising from irregularities in the mechanism will scarcely appear in the result.

The syren may be set in action by the flow of air or gas from a gasometer, or by means of a stream of water. When plunged entirely in water, it will yield the same tones as in air, a circumstance which suggested to the inventor the name of this instrument.

Variations in the number, the form, and the size of the apertures of the rotating disc produce corresponding variations in the *quality* of the resulting notes; the *pitch* or rapidity of vibration may remain the same, but the quality or *timbre* may be very different. This is occasioned by some ill-understood connection between the molecular constitution of bodies and the sounds which they emit, whereby we are able to call things by their right names from their sounds. It is a most obscure and difficult subject, and the variations in timbre in the syren do not serve to enlighten it. If the spaces between the apertures in the rotating disc be very small, the tones approach in character to those of the human voice; if the spaces be large, the tones resemble those of a trumpet. A number of experiments with the syren seems to

show that the extreme limits of the human voice in males vary from 384 to 1266 vibrations per second, and in females from 1152 to 3240. The highest note in music is about the 14th C* (five octaves above the middle C of the pianoforte), and this is due to 8,192 vibrations per second; but much higher tones can still be heard. Savart has produced tones due to 48,000 vibrations per second.

66. Let us now inquire further into the relation between musical pitch and the rapidity of vibration. It has been already stated (62), that whenever two notes differ by an *octave*, the upper is due to two vibrations for every one vibration of the lower note; and as 8,192 vibrations per second produce the note called C, it follows that the next C below this contains 4,096, the next 2,048, the next 1,024, then 512, 256, 128, 64, 32, and 16 vibrations per second, the last number being generally considered the lowest note in music, and is also C, being nine octaves below that first mentioned.

67. It would thus appear that in any series of notes taken at equal *intervals*, or in arithmetical progression (according to the musical notation), the vibrations really increase or diminish in *geometrical* progression; for that which the musician calls equal *intervals* or *differences* of pitch, actually indicates equal *ratios* between the times of the vibrations. But although this is true not only of the intervals called octaves, but also of those called *thirds, fourths, fifths*, &c. (if perfect), yet it is not true of those called *single tones*; for, if we interpolate six geometrical means between any note and its octave, these will not be the six intermediate notes used in music. The reason for this is as follows :—

We have said (61) that, to constitute a *musical* note, the waves or pulses of air must recur in a *regular* manner. They need not be all equal in intensity or at equal intervals, but their whole cycle of changes (if any) must occupy a very short fraction of a second, and recur in exactly equal periods.

* So called from its number of vibrations per second, being the 14th power of 2, or $2^{14} = 8,192$. All other powers of 2 also give the note C.

Now, when two notes are heard together, they cannot form a compound sound, fulfilling this condition, unless their times of vibration bear a simple numerical ratio to each other, so as to have a short common multiple which forms the cycle of changes above mentioned, and must not be longer than $\frac{1}{16}$th of a second. Accordingly, all the intervals called *harmonic* arise from some very simple ratio between the vibrations, as, for instance, the *octave* already mentioned; the *fifth*, when 2 vibrations of one note exactly correspond to 3 of the other; the *third*, when 4 vibrations correspond to 5; the *fourth*, when they are as 3 is to 4, &c. But two vibrations which are incommensurable, or have no common multiple (or a very long one), produce by their combination such a total irregularity, however regular they may each be separately, that the compound loses all musical character, and becomes a mere *noise*.

Hence we see that it is the object of the musician to fix on such notes as may afford, among themselves, the greatest number of simple commensurable ratios. This object would be entirely defeated by a geometrical progression (that is, by dividing each octave into *equal* intervals), for no geometrical means that can be inserted between any number and its double will be commensurable with those numbers, or with each other; so that all notes thus chosen must be discordant.

But the required object is best attained by inserting between a note and its octave, or double vibration, six other notes which are respectively due to $1\frac{1}{8}$, $1\frac{1}{4}$, $1\frac{1}{3}$, $1\frac{1}{2}$, $1\frac{2}{3}$, and $1\frac{7}{8}$ more vibrations per second than the lower note, which is called C, or *Do*, while the others represent the remaining notes of the gamut, namely,

D	E	F	G	A	B.
Re	*Mi*	*Fa*	*Sol*	*La*	*Si.*

Hence, supposing that whatever be the number of vibrations per second necessary to produce the note C, we agree to

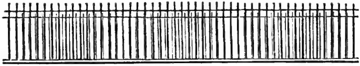
represent it by unity or 1, then the numbers necessary to produce the other seven notes of the octave above will be as follows :—

$$\text{D} = \tfrac{9}{8},\ \text{E} = \tfrac{5}{4},\ \text{F} = \tfrac{4}{3},\ \text{G} = \tfrac{3}{2},\ \text{A} = \tfrac{5}{3},\ \text{B} = \tfrac{15}{8},\ \text{C} = 2.$$

It will be observed, that the seven intervals or *tones* are by no means equal, for these numbers do not form a geometrical progression. Thus the ratio between C and D is that of 8 : 9, while that between D and E is rather less, namely, as 9 : 10; the next, or that between E and F, is only as 15 : 16; the next, or that between F and G, as 8 : 9; that between G and A, as 9 : 10; that between A and B, as 8 : 9; and the last, or that between B and C, is only as 15 : 16. Thus we see that the intervals between E and F, and between B and C, hardly exceed the half of each of the other intervals. Hence the reason that these two intervals do not, like the others, admit of subdivision into semi-tones.

68. A very remarkable proof of the vibratory nature of sound is heard when two notes very nearly, but not quite unisonant, are sounded together. A periodical interruption of the sound called a *beat*, occurs at intervals, which are *longer* the nearer the two notes approach to perfect identity, and may often be as long as half a second or more. To understand this, we must remember that each pulse or vibration of air consists of *two* contrary motions *to* and *fro*. Now, if one source of sound tend to produce the forward motion exactly when the other source would excite a backward motion, and *vice versâ*, the two, if equal, will annihilate each other, and *two sounds will produce silence*. But with two notes, very slightly differing in pitch, this must occur at certain regular periods, between which the contrary effect takes place, and the two vibrations coincide so as to reinforce each other. The effect is precisely similar to that which is *seen* when two very regular sets of parallel lines, one having rather wider spaces than the other, are superposed. Thus, two iron gratings or railings, Fig. 36, which, though really

Fig. 36.

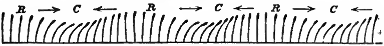


of equal intervals, are made to appear slightly different from the effect of perspective, produce the appearance of broad *beats*, or alternations, in one of which the bars coincide and conceal each other, while in the next they fall into each other's intervals. Or to take a closer analogy from the sense of hearing instead of that of sight: if we listen to a train drawn by two locomotives whose driving wheels differ slightly in size, their beats are heard distinctly for a few seconds, they are then lost in confusion for a short time; they are again heard distinctly, and again blended together alternately. Now, suppose any vibrating body to strike the air 100 times in a second and another 104 times in the same space, the latter will produce a sound about one-third of a tone sharper than the former; the waves of sound will coincide and reinforce each other 4 times every second, and will oppose, and, if equal, will destroy each other 4 times in the same period, thus producing an audible beat about as rapid as that of a watch.

69. In our introductory treatise on Natural Philosophy, we have shown the method by which the velocity of sound in air has been ascertained. At the temperature of 62° sound travels at the rate of 1,125 feet per second. It has been stated (61), that when a given note is sounded in air, the sound is propagated in *waves* similar in character to those which may be so beautifully studied when the wind is blowing over a field of standing corn. (See Fig. 37.) Now, when it is said that sound travels at the rate of 1,125 feet per second, it is not meant that the particles of air move through that distance any more than the ears of corn travel from one end of the field to the other; it is only the *form of*

the wave which so travels. It is the same with the particles of air; their individual movement is confined within narrow limits, but the effect of this movement is propagated from particle to particle with the rapidity of 1,125 feet per second. As soon as the particles first disturbed have moved to such a distance as their elasticity will permit, they return to their former position, and acquire in so doing a momentum sufficient to carry them a certain distance in the opposite direction, and by this means an oscillating or vibratory movement is established. Each particle is disturbed a little later than the one preceding it, and thus the particles are in different states of motion, some moving onwards while others are moving backwards, the two sets being separated by particles at rest, or in the act of *turning* from the completion of one movement to commence the next. Now these turning sets of particles are alternately more *condensed* and *rarefied* than in their natural condition. (See Fig. 32.) Those which have just commenced their backward motion are rarefied as the ears of corn at R R R, Fig. 37, and those which are

Fig. 37.



beginning their forward motion are condensed as at C C C.

This has given rise to the term *wave* of sound, a wave being understood to include particles in all the various states of vibration, each wave being exactly similar to all the others for any given note. *The length of a wave* is the distance between any two particles which are in precisely the same stage of vibration. It matters not whether we measure it from the most *forward* to the most forward set of particles, or from the most *backward* to the most backward set; or from one place of greatest *rarefaction* to the next, or from one place of greatest *condensation* to the next; just as it is a matter of indifference, in estimating the length of a wave of

water, whether it be taken from one *elevation* to the next, or from one *depression* to the next.

Waves of water do not all travel with the same speed, their speed being proportional to the square root of their length, so that, the slower or less frequent the oscillation, the faster does it travel; those of the ocean, for instance, travel faster than those of the English Channel, and these than the waves of a river.

Waves of air, however, whatever their frequency, all travel with the uniform speed of about 1,100 feet in a second. Hence, when we know their frequency, or how many of them arrive at and pass a fixed point in a given time (such as a second), we may at once find their length, which is 1,100 feet divided by their number per second. Thus, the C above the tenor C is produced by 512 vibrations per second; 512 waves fall on the ear in that time, during which each would travel 1,100 feet, so that this distance contains 512 waves, each of which must accordingly occupy about 2 feet 1 inch. Consequently, every time this note is sounded on *any* instrument, the air which conveys this note to our ears is thrown into waves, each of which measures about 2 feet. All the innumerable particles of air between us and the instrument form a series of little pendulums, the amplitude of whose oscillations depends on the *loudness* of the sound, and is, in all cases, very minute; but the distance from each particle to the next, which is in precisely the same part of its oscillation as from C to C or R to R, Fig. 37, depends entirely on the *pitch*, and is, in this case, about 2 feet. In the same way we find the waves of the gravest note to be about 64 feet long, and those of very shrill sounds to be less than an inch.*

* A very curious effect of sound when the observer is in rapid motion was brought before the notice of the British Association in 1848, by Mr. Scott Russell. He found that the sound of a whistle on an engine, stationary on a railway, was heard by a passenger, travelling in a train in rapid motion, to give a different note, in a different key from that in

70. When waves of sound meet any fixed surface tolerably smooth, they are reflected according to the law of equal angles of incidence and reflexion.* In this way *echoes* are produced. Between two parallel surfaces a loud sound is reflected backwards and forwards, and several echoes are audible. When the parallel surfaces are much nearer together, as the walls of a room, although a larger number of echoes are produced, yet they follow each other too rapidly to be distinguished, and as they arrive at the ear after *equal* intervals, they produce a *musical note*, however unmusical the original noise may have been. Hence all the phenomena of *reverberation*. The pitch of the note depends solely on the distance of the two walls that produce it, and may be calculated therefrom.

A noise may also produce a musical echo by being reflected from a large number of equidistant surfaces receding from the ear, so that the sound reflected from each surface may arrive successively at equal intervals. Thus a shrill ringing will be heard on stamping near a long row of palisades. A fine instance of the same kind is said to occur on the steps of the great pyramid. If the distance from edge

which it was heard by the person standing beside it. The same remark applies to all sonnds. The passenger in rapid motion hears them in a different key, which might be either louder or higher in pitch than the true or stationary sound. Now, as the pitch of a musical sound is determined by the number of vibrations which reach the ear in a second of time, if an observer in a railway train move at the rate of 56 miles an honr *towards* a sonnding body, he will meet a greater number of undulations in a second of time than if he were at rest, in the proportion which his velocity bears to the velocity of sound. But, if he move *from* the sounding body, he will be overtaken by a smaller number in that proportion. In the former case he will hear the sound a semitone higher, and in the latter a semitone lower than the observer at rest. In the case of two trains meeting at this velocity, the one containing the sonnding body and the other the observer, the effect is doubled in amount. Before the trains meet the sound is heard two semitones too high, and, after they pass, two semitones too low, being a difference of a major third.

* See Introduction to Natural Philosophy, secs. 35 and 45.

to edge of each step were two feet one inch, the note yielded would be the tenor C, because each echo having to go and return, would be four feet two inches later than the previous one, which is the length of the waves of that note. But as the steps gradually diminish in size upwards, the echo, if produced and heard at the bottom, must gradually rise in pitch.

These facts explain the principle of those wind-instruments in which there is no vibrating solid. The vibrating body is not the pipe, but the air contained in it. An agitation produced in the air at one end of the pipe is communicated to the other end, and reflected backwards and forwards from end to end, producing isochronous (or equal-timed) impulses, the frequency of which depends entirely on the *length* of the pipe. Hence all organ-pipes of the same length yield the same note as to *pitch*, its quality only being affected by the form or material of the pipe. It will thus be at once perceived that the lowest C (the waves of which are 64 feet long) requires a pipe of 32 feet to produce it; and that all notes, from this to the shrillest whistle, are easily calculated, by dividing 550 feet by the length of the pipe.

71. Some very remarkable effects of sound are produced in the phenomena of *sympathetic* vibration, numerous instances of which must be familiar to the reader. If a flute be sounded in the same room with a piano, the notes of the flute will cause some of the wires to vibrate. The waves of sound set in motion by the flute produce motion in those very wires which yield the same notes as are being played. If the voice be pitched to the same note as that yielded by a glass goblet, the former will set the latter ringing. And to take a still more remarkable instance, if two pendulum clocks standing against the same wall be both wound up, and one set going while the other is at rest, the small vibrating impulses of the going clock will gradually communicate motion to the pendulum at rest, and in the course of some hours the latter will be found in full swing.

72. It will be seen from the foregoing survey, that the atmosphere, like a vast and complicated machine, has a variety of movements, the result of omniscient design. Some of the latest and most valuable discoveries respecting the motions of the aërial currents beautifully illustrate a passage in Scripture: "The wind goeth towards the south, and turneth about unto the north; it whirleth about continually, and the wind returneth again according to his circuits." * Amidst all the mutations of science, it is cheering to the student to notice, that no sooner is a natural law brought to light, and fairly established, than we immediately perceive its harmony with sacred truth. Whatever discrepancies may seem at present to exist, arise from the imperfection of our knowledge of natural laws, and will, as science advances, gradually be cleared away.

* Eccles. i. 6.

APPENDIX.

ON THE ANEMOMETER.*

It is a matter of considerable importance to mechanical science to be able to determine the velocity or force of the wind. Its direction is indicated by that ancient instrument, the weathercock, which consists of a vane of thin metal (formerly made in the shape of a cock, whence the name), and an arrow, turning freely at the upper extremity of a fixed vertical rod, the vane being on one side and the arrow on the other, so that the vane takes a position in the direction of the wind, and the arrow points to the quarter from which it blows. The first instrument invented for the purpose of measuring the force of the wind seems to have been by Dr. Croune, in 1667; but this did not answer the purpose intended. Better instruments were invented by Wolfius and other scientific men during the last century; but as their most valuable features have been preserved in modern instruments, it is not necessary to notice them here, further than to state, that in most of these contrivances the velocity of the wind was measured by its mechanical effects. The compression of a spiral spring, the elevation of a weight round a centre acting at the arm of a variable lever, were the chief means employed to balance, and consequently to measure, the force of the wind. The spring, however, which,

* From ανεμος, the wind, and μετρον, a measure. We are indebted for this essay chiefly to the work entitled "The Tempest," already referred to at p. 83.

from its simplicity, has been commonly used, is liable to this objection, that it diminishes in elasticity by frequent compression, and thus the scale by which its force is ascertained must be constantly varying. To remedy this defect, there has sometimes been substituted for the spring a bag of air communicating with a glass tube in the form of a lengthened U, containing a liquid, which is depressed in one leg and raised in the other in proportion to the compression of the air in the bag, thus affording a measure of the compressing force. Leslie's anemometer depended on the principle, that the cooling power of a stream of air is equal to its velocity. Another instrument depended on the evaporation of water, the quantity evaporated in a given time being proportional to the velocity of the wind. The raising of a column of fluid above the general level of its surface is the principle of Dr. Lind's anemometer, Fig. 38. It consists of two glass tubes, about 9 inches long and $\frac{4}{10}$ths of an inch in diameter, connected at their lower extremities by another tube of glass only $\frac{1}{10}$th of an inch in diameter. To the upper extremity of one tube is fitted a thin metal cap, bent at right angles, so that its mouth may receive the current of air in a horizontal direction. Water is poured in at the mouth till the tubes are nearly half full, and a scale of inches and parts of an inch is placed between the tubes. When the wind blows in at the mouth of the cap, the column of water is depressed in the tube below the cap, and elevated to a similar extent in the other tube, so that the distance between the surfaces of the fluid in each tube is the length of a column of water, the weight of which is equal to the force of the wind upon a surface equal to the base of the column of fluid. The object of the small tube which connects the two larger ones

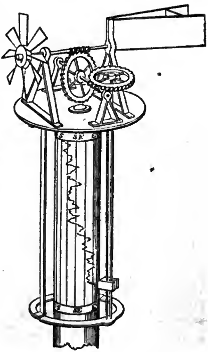
Fig. 38.

is to prevent the oscillation of the fluid by irregular blasts of wind. The absolute velocity of the wind is deduced from the height of the column of water, or it may be ascertained from the tables constructed for the purpose. Thus, according to Dr. Lind, a column of water 0·025 inch, or a fortieth of an inch high, exerts a pressure of rather more than 2 ounces 1 drachm upon a square foot of surface, and balances the effect of a gentle wind moving at the rate of about $5\frac{1}{2}$ feet in a second, or not quite 4 miles an hour. When the column of water is one inch high, the force of the wind on a square foot is nearly $5\frac{1}{4}$ lbs., its velocity $32\frac{1}{2}$ miles an hour, and its character a high wind. When the column marks 3 inches, the force is upwards of $15\frac{1}{2}$ lbs. on the square foot, the velocity above $56\frac{1}{4}$ miles per hour, and the character a storm. At 9 inches the force on the square foot is stated to be 46 lbs. 14 oz., the velocity $97\frac{1}{2}$ miles an hour, producing a most violent hurricane. Thus it will be observed that in the greatest storms the difference between the atmospheric pressures on the windward and leeward sides of any object does not amount to $\frac{1}{80}$th of the pressure of the leeward side, for that is capable of supporting a column of about 33 feet of water.

Of late years the most common forms of anemometer are those by Dr. Whewell and Mr. Osler. The general arrangement of Whewell's anemometer will be understood from Fig. 39, in which it will be seen, that, by means of a vane, a windmill fly is constantly presented to the wind in whatever direction it may blow, and the fly of course revolves with greater or less rapidity, according to the velocity of the current. An intermediate train of wheels, set in motion by the fly, causes a pencil to descend over a fixed cylinder, leaving thereon a trace of variable length, according as the wind is more or less strong. 10,000 revolutions of the fly cause the pencil to descend only $\frac{1}{20}$th of an inch. The surface of the fixed cylinder is japanned white, and is divided into 16 or 32 equal parts by means of vertical

lines, the intervening spaces corresponding to 16 or 32 points of the compass, and a mark left by the pencil upon one or more of these spaces shows the direction of the wind. The pencil has two motions, the first from above downwards, and this increases in rapidity as the wind blows more strongly, and by the extent of its depression registers the whole amount of wind that has been blowing. The second motion depends on the changes in the direction of the wind, and the pencil and its frame being carried round by the vane, the direction is registered by this cross movement. In this arrangement, therefore, the vane, the windmill-fly, the intermediate train of wheels, and the pencil, all obey the direction of the wind; while the cylinder which marks the points of the compass remains fixed, so that the pencil, in descending and moving about with the wind, thus traces an irregular line on the cylinder. If the fly revolve in the simple proportion of the velocity of the wind, the length of line marked by the pencil is proportional to the space which would be described by a particle of air in a given direction in a given time, such as one day, taking into account the strength of the wind and the time for which it blows.

Fig. 39.



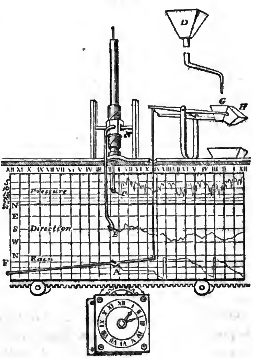
The line marked by the pencil upon the cylinder is not a single line, but a broad irregular path. This is occasioned

by the wavering of the wind. The vane is in almost constant motion, swinging to and fro through an arc often not less than a quarter of a circle; but the middle of the line which gives the mean direction, can readily be ascertained, while the length of the line is in proportion to the product of the velocity of the wind and the length of time during which it blows in each direction, which product is called its *integral force.*

The amount of friction in this machine is very considerable, arising from perpetual screws working in toothed wheels, for the purpose of converting the rapid motion of the fly into a slow, descending, vertical motion, again carried out by a thread turning within a moveable nut. There is also the friction of the pencil, attached to this nut, pressing with sufficient force to leave a trace on the fixed cylinder. Hence, when the force of the wind is small, the fly would experience a greater amount of comparative retardation than with strong gales.

Osler's anemometer traces the direction of the wind and its pressure on a given area, together with the amount of rain, on a register divided into 24 portions, corresponding to the 24 hours of the day. A portion of one of these register-papers is shown, Fig. 40, the central part of which is marked with a series of lines corresponding to the cardinal points of the compass. This is for indicating the direction of the wind. The upper portion of the paper registers the pressure, and is graduated by a series of lines corresponding to the pressure in pounds on the square foot. The lower portion of the paper registers the quantity of rain. The whole length of the paper is divided for the hours of the day into 24 parts, by lines crossing the former at right angles. A new register-paper is placed on a board, and accurately set every day, and the board is carried along by means of a clock mechanism, behind three pencils A, B, C, which may be considered as the fingers or indexes of the machine. The board, which is placed upright, as in the

Fig. 40.

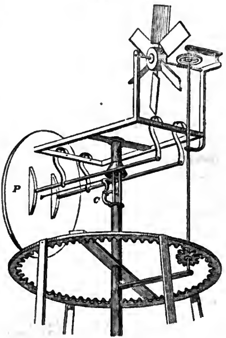


figure, moves on friction-rollers, and is thus moved along as the time advances.

The pencil B is the index of direction. The method by which the instrument is turned, so as to obey the direction of the wind, will be seen in Fig. 41. A set of vanes or sails revolve vertically in a plane at right angles to that of the pressure-plate P, and drive a cog-wheel, which, by rolling on a fixed cogged circle, turns all the rest of the apparatus round, till the vanes are presented edgewise to the current, so as not to be turned by it either way, when the pressure-plate being at right angles to the vanes, is acted on with full effect. As the vanes turn in the direction of the wind, a spiral worm on the shaft, near its lower end, raises or lowers the nut N, Fig. 40, which does not turn round, and from which hangs the arm carrying the middle pencil B, which thus traces a mark on one of the long lines of the register, if the wind be blowing towards one of the cardinal points, or a mark between these lines, if it be blowing from intermediate points, such as N.N.W., N.W., &c., which may be represented by fainter lines parallel with the others.

The method by which the pressure-plate P, Fig. 41, is always made to face the wind, has been already described. This plate is suspended by means of four flexible springs, each of which is double, and consists of a delicate spring, to be acted on by gentle winds, and a stronger one to receive the pressure of violent winds. By this means currents of only one mile an hour are measured, and the pressure of the wind in violent gales is also recorded. The motion of the plate is communicated to the register below by a wire connected with the bell-crank C, with another wire descending through the hollow upright shaft, and kept stretched by a spiral spring. To this wire is attached the upper pencil C, Fig. 40, which thus descends lower the more the pressure-plate P is pushed back, and returns to the top of the paper when the pressure ceases. The distance to which the pencil is thus depressed, represents by means of a scale of parallel lines, shown in Fig. 40, the pressure of the wind in pounds on the aréa of one square foot, or its velocity in miles per hour.

Fig. 41.



The pencil A registers the rain in a similar manner. The rain, after falling into the vessel D on the roof, flows into G, one of the two divisions of a gauge balanced on an axis, and supported by a second balance. As the water accumulates,

this second balance begins to descend, and so raises the upright rod to which the lever F A is attached. This lever F A carries the pencil which by this action is raised, showing upon the lowest set of parallel lines the quantity of water collected in the gauge. When this quantity becomes equal to a certain depth of rain, or to a certain number of cubic inches on a foot square, the small gauge oversets, the water is discharged, and the other compartment H of the gauge is brought under the pipe. The pencil then returns to its first position at the bottom of the paper, and begins to rise on the scale as the rain is collected. In a trace of this kind it will be seen that, the more rapidly the rain falls, the sharper will be the angles formed by the trace of the pencil; but if the rain be slow and gradual, the elevating or diagonal lines will be drawn out into a considerable length; and when no rain falls, a horizontal line will be drawn, as shown in Fig. 40, from VI. to $\frac{1}{4}$ after VIII., and from X $\frac{1}{2}$ to I.

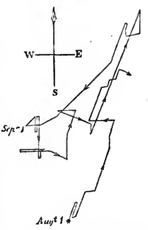
It will be seen, then, from this arrangement, that as the register is constantly and hourly moved along behind the three pencils, a continued record or trace of the direction and pressure of the wind, together with the amount of rain, is left on the paper. Figs. 40 and 41 are intended to convey a general idea of Mr. Osler's arrangement in the Royal Exchange, London, where the register-paper is made to last a week. When the author visited the Meteorological Observatory at Greenwich a few years ago, he noticed that the register was placed horizontally on a table, and, being on a larger scale, it was changed every day.

By means of such an instrument we ascertain the *direction*, the *duration*, and the *force* of the wind. It is necessary, however, for the purposes of science, that the *integral* of the wind be deduced from each point of the compass; that is, to ascertain the entire quantity of wind which has blown from each point during a given period. Now if the force of the wind were constant, the integral would be obtained by multiplying the length of time that the wind is blowing by the velocity with which it moves.

The integral of the wind, or the total quantity as measured by its intensity and duration jointly, may be thus illustrated. If the intensity or force of one wind be to that of another as 2 to 3, and if the former wind last 6 hours, and the latter only 2, the integral of the former is double that of the latter, for it has blown twice as much air over the place; for supposing the second wind to be opposite to the first, it must blow for 4 hours before it will carry back all the air which the first had blown over. The integral, therefore, is proportional to the product of the mean intensity or velocity, and the duration multiplied together.

In a similar manner the area of a rectangle is proportional to its length and breadth taken jointly. Now if we have such a figure, whose length represents the *duration* of the wind, while its breadth represents the *force* or *velocity*, as this force is constantly varying, the breadth of the figure must also vary, in order that its area may still represent the *integral* of the wind correctly. It is the object of Osler's anemometer to describe such a figure. In Whewell's instrument, on the contrary, the integral is represented simply by the depth which the pencil descends. In this instrument no attempt is made to record the *time* during which each wind blows, the *times of its changes*, or its *force* at any given moment, but merely the order of its changes of direction, and the integral or entire quantity that blows from each point, or rather from each rhumb or division of $11\frac{1}{4}$ or $22\frac{1}{2}°$. This is shown by the length of pencil-trace described in each vertical division of the cylinder measured vertically, not following the windings of the track. These windings must be neglected as far as they are confined to one rhumb or division, the centre of which corresponds to one of the 16 or 32 points of the compass. All winds, therefore, not deviating more than $5\frac{1}{8}°$ from any one of these points, if 32 be used, or $11\frac{1}{4}°$ if 16 be used, are regarded as blowing exactly from that point. This is a defect common to all anemometers now in use, but by increasing the number of subdivisions, the results will be more accurate.

Fig. 42.



Having obtained, by means of Whewell's instrument, the integrals or lengths of line described by the pencil in each division during a certain period, we may lay down these lengths, or proportionate ones, in their proper order and direction, so as to form a continued crooked line, which expresses all the quantities and changes of the wind, and is called the *type* of the wind for that particular place and period. Fig. 42 represents the type of all the wind that blew over Plymouth during the month of August and part of September, 1843. Such a line may be regarded as the path that would have been described by a vessel drifting upon a still lake during that period, provided it moved with a speed always bearing a constant ratio to that of the wind. If the two ends of this line be joined by a straight line, this will show the direction of the *resultant* or average effect of all the winds felt at Plymouth during that period, which in this case is N. 23° E., or about equivalent to a S.S.W. wind. This average direction is not the *prevailing* direction of the wind, or that in which it most commonly blows; for the prevailing winds may be very gentle, and the greater force of those from the opposite quarter may more than compensate for their shorter duration, so that the average direction as regards the integral, or time and intensity taken jointly, may be very different, or even opposite to the average direction, if time alone be considered. In this country, however, both these averages have nearly the same direction; the latter, or time average, being equivalent to a wind blowing from some point between S. and W.; and the former, or true average, though apparently very variable when the resultants of different months or seasons are compared, yet in the type

of a whole year, its general direction is found invariably to run northward, and mostly eastward from the starting-point. In the present state of the inquiry there is some discrepancy between the results obtained by different instruments; Whewell's placing the mean direction for three years nearer N. than E., while Osler's makes it nearer E. than N. The latter is more likely to be correct, because in Whewell's instrument the velocity of the windmill-fly does not bear a constant ratio to that of the wind, but is more than proportionately faster in a quick than in a slow wind, so that the distance which the pencil descends being proportional to the revolutions of the fly, cannot correctly represent integrals of wind; that is to say, the spaces through which it descends during two successive periods do not necessarily bear the same ratio to each other as do the quantities of wind that have passed over the instrument during those two periods. This objection is surmounted in Osler's instrument, which is driven by a clock, and merely directed or regulated by the wind.

But if Osler's instrument is more correct than Whewell's, it is more difficult to represent the results in the useful form above described. If the instrument be in perfect order, the upper trace made on the paper by the pencil c, Fig. 40, should be such that its ordinates* are proportional to the velocity of the wind; that is, the ordinates at any two different moments should bear the same ratio to each other as did the velocities of the wind at those two moments. In this case the total amount of wind passing over the instrument during different periods, will be proportional to the areas of the portions of curve traced during these periods; that is to say, the spaces contained between the curve, the base-line, and the two ordinates at the beginning and end of each period. It is only by measuring and comparing these areas, that we can

* The ordinate of any point of the curve, is its least, or perpendicular distance from the axis, or base line, which in this case is the top of the paper.

obtain the proportion of the integrals of wind during different periods of time.

To lay down a type of the wind similar to Fig. 42, we must divide the periods in such a manner, that during each period the direction of the wind may have been constant or confined within certain limits, such as two rhumbs or $22\frac{1}{2}°$, or one rhumb, $11\frac{1}{4}°$. For this purpose, that part of the register-paper which registers *direction* must be divided by 16 or 32 longitudinal lines, so that when the vane points to any one of the 16 or 32 principal points of the horizon, the pencil B may rest midway between two of these lines. We must then note all the points where the pencil-track intersects these lines, and from every such intersection raise a perpendicular to the top of the paper; these perpendiculars will evidently divide the upper curve, or that of force, into portions, each of which may be regarded as belonging to one wind only; for during its description the wind did not deviate more than $5\frac{1}{8}°$ (if we use 32 points, or $11\frac{1}{4}°$, if we use only 16), on either side of a certain point. By ascertaining the areas of these different portions, and drawing lengths of line proportional to those areas, placing those lines in their proper directions and in their proper order, we may obtain a type of the wind more correctly than by the method before described.

The integrals of the wind have hitherto been referred to only as relative quantities, admitting of comparison only with each other. They have, however, absolute values easily comparable with our common standards or measures. If a pressure-plate, acting on a spring, as in Osler's anemometer, be fixed to an extremity of a long beam, or some machine by which it could be moved through the air with any required velocity between 1 mile and 50 miles an hour, it matters not whether the path be straight or circular, provided the plate always face the direction in which it moves. If the air be still, the effect on the plate is the same as if it were at rest, and received a wind of a known velocity upon its surface.

By this means it can be discovered what velocity of wind is required to produce any amount of compression on the spring, such as may be obtained by placing weights of known value on the pressure-plate. In this way a scale of the velocities or force of the wind may be constructed by the different degrees of compression of the spring, or a fusee or snail-shaped pulley, the radii of which vary in such a manner that when it is pulled round by a cord from the pressure-plate, a circular pulley, fixed on the same axis with it, may move through equal spaces for equal differences in the wind's velocity; so that a cord wound round this second pulley may pull the registering pencil C, Fig. 40, to such distances from the bottom of the paper as shall always bear the same ratio, and that a known ratio to the wind's velocity. Some such contrivance is necessary before the integrals can be measured by means of the areas of the curve. Suppose that the pencil is one inch from the top of the paper when the wind blows at the rate of 10 miles an hour; two inches when it is blowing at 20 miles an hour, and so on; and that when the paper is moved, or allowed to move forward by the driving weight of the clock at the rate of one inch an hour; then every square inch of surface included between the curve of force and the top of the paper denotes that 10 lineal miles of air have blown over the instrument; so that, by measuring the area of any portion of this surface included between any two ordinates, we find the *absolute integral* in miles, or the number of miles of air that have passed over during the period in which that portion of the curve was traced. In this way absolute values in miles may be assigned to all the lines which compose any type of the wind; and on measuring by the scale thus obtained the length of the resultant or line joining the two ends of the type, we obtain not only the direction, but also the extent in miles of the entire movement of air produced by the combined effect of all the winds that have blown during the period for which the type was constructed. By this means it was ascertained that the resultant of all the

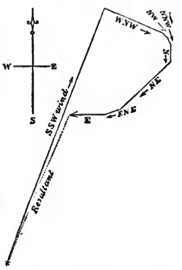
winds that blew over Greenwich during the year 1841 was equivalent to the passage of 47,900 miles of air towards E. 28° 30′ N. In 1842 the direction of the resultant was E. 27° N., and its length 36,750 miles. By dividing these numbers by the number of hours in a year, the total effect of the wind in 1841 is found to be equivalent to a constant current towards E. 28° 30′ N., at the rate of 5·4 miles an hour; and in 1842 towards E. 27° N., at the rate of 4·2 miles an hour; or in other words, as if there had blown during those two years a constant wind from W.S.W. ½ S. at 4¾ miles an hour.

But the average velocity of the winds at Greenwich during the former year was 18·7, and during the latter 18·3 miles an hour; for the whole integrals of wind for those years, as shown by the length of their type-line, measured along all its windings, was in 1841, no less than 167,322 miles, and in 1842, 159,950 miles; showing that the whole movement of the air in this country is about four times as great as its resultant or effective movement. The more variable the wind may be at any place, the smaller the proportion of it that will be effective; and if these observations could be made on the open ocean within the range of the constant trade-winds, the type would probably (when not interrupted by a hurricane) be a straight line, and the numbers expressing the total and resultant integrals of wind would be equal.

The direction or length of the resultant for any given period may be obtained more simply than by laying down such a type as Fig. 42; for as the lines in whatever order they may be placed will eventually lead to the same point, the figure may be simplified by collecting and summing up all the integrals that belong to the same wind or point of the compass, or that fall within the same angle of 11¼° or 22½°, but the smaller the angle the better; and then drawing lines proportionate to the 16 or 32 sums thus obtained, which lines placed in any order, but in their proper direc-

tions, will give the same resultant as if the whole type were drawn. But as some of the lines thus drawn are parallel to others, it is not necessary to draw more than half of them, subtracting from each one that which is parallel to it. So that whatever number of points be used, the number of their integrals can always be reduced one-half, by subtracting each non-effective wind, or each one that is less than its opposite, from that opposite, the remainder being alone retained. Thus, Fig. 43 contains all the effective lines of Fig. 42 treated in this manner, and gives the same direction and length of resultant; by which means much labour is saved.

Fig. 43.



Some observers prefer finding the resultant, direction, and length, by trigonometrical calculation, instead of by construction; but in such case, in order to abridge their labour, they not only reduce the number of operations one half in the way above mentioned (which introduces no error), but attempt to reduce their number still lower, in some cases to the four cardinal points only, by methods which are more easy than accurate. For instance, they add together the integrals of all the points between N.E. and N.W., with half of the N.E. and N.W. integrals, and call the sum north. In the same way half the sum of the N.E. and S.E. integrals, together with the whole sum of those for the intermediate points, is taken as the east integral. This is erroneous, for it is evident that, unless the integrals of the winds, thus added together, be symmetrically equal, two and two on each side

of the cardinal point, their mean direction cannot coincide with that point; and in every case their sum must be greater than their resultant, and therefore the value thus obtained must always be too large; and if ever correct in direction, it can only be so by a chance compensation of opposite errors.

The true resultant may, however, be found by calculation; and the method of doing so is by no means tedious or difficult. The sum of the integral forces of each effective wind, that is to say, the difference of the sums for every pair of opposite winds, must, except when it is directed towards a cardinal point, be resolved into two distinct forces, together equivalent to itself, but directed towards the two nearest cardinal points. This will be effected by multiplying it separately by two of the following seven constant numbers, which are all that will be required, for treating in this way, the forces for 32 points:

For a point next a cardinal point......	0·98078	and	0·19509
For the second from do.	0·92388	,,	0·38268
For the third from do...............	0·83147	,,	0·55557
For a sub-cardinal point (as S.W.).....	0·70711		

In the latter case only one multiplier is used, because the two resolved forces are equal. In the other cases the larger resolved force thus found is directed to the nearest cardinal point.

All the forces being thus reduced to equivalent ones, either parallel or perpendicular to the meridian, all the former must be collected together, that is to say, all the northward and all the southward forces must be separately summed up, and the smaller of these sums, in this country generally the southward, subtracted from the larger, the remainder being the whole effective *meridional* movement of air over the place, and during the time, in which the register was kept. In the same manner must the eastward and westward forces be collected, and their difference will represent the whole

effective movement *across* the meridian, which in this country is generally eastward.

This process might of course be greatly abridged by the use of logarithms; but to render it intelligible to every reader we will give an example, worked out by the simplest rules of arithmetic.

The total amount of wind blowing over Devonport, during 1842, from each of the 16 principal points (or within $11\frac{1}{4}$ degrees of it), was found to be as follows :—

		Miles.		Miles.		Miles.		Miles.
From	N...	6,829	E...	7,427	S...	17,000	W.	8,599
,,	N.N.E.	4,289	E.S.E.	4,144	S.S.W.	7,437	W.N.W.	12,788
,,	N.E.	7,482	S.E.	11,488	S.W.	16,586	N.W.	28,400
,,	E.N.E.	2,448	S.S.E.	11,500	W.S.W.	6,156	N.NW.	7,377

We first get rid of half these numbers, by subtracting them from their opposites, thus :—

	Miles.		Miles.
From S.	17,000	From S.S.W.	7,437
Take N.	6,829	Take N.N.E.	4,289
S.	10,171	S.S.W.	3,148
From W.	8,599	From W.N.W.	12,788
Take E.	7,427	Take E.S.E.	4,144
W.	1,172	W.N.W.	8,644
From S.W.	16,586	From W.S.W. ..	6,156
Take N.E.	7,482	Take E.N.E.	2,448
S.W.	9,104	W.S.W.	3,708
From N.W.	28,400	From S.S.E.	11,500
Take S.E.	11,488	Take N.N.W.	7,377
N.W.	16,912	S.S.E.	4,123

Of these remainders, or effective forces, two being in the direction of cardinal points (S. and W.), require no further resolution. The others must be resolved by applying some of the constant multipliers given above, only three of which

will, however, be required, because in this case the winds were only distinguished into 16 classes instead of 32, thus :—

S.S.W.	3,148	multiplied by 0·92388	gives	2,808	S.
		the same × by 0·38268	=	1,205	W.
S.W.	9,104	× by 0·70711	=	6,438	S.
		× by the same	=	6,438	W.
W.S.W.	3,708	× 0·92388	=	3,426	W.
		× 0·38268	=	1,419	S.
W.N.W.	8,644	× 0·92388	=	7,986	W.
		× 0·38268	=	3,308	N.
N.W.	16,912	× 0·70711	=	11,959	W.
		× by the same	=	11,959	N.
S.S.E.	4,123	× 0·92388	=	3,809	S.
		× 0·38268	=	1,578	E.

Collecting all the forces that are parallel, therefore, we find :—

Northward forces.	Southward forces.
10,171	3,308
2,808	11,959
6,438	
1,419	Sum 15,267
3,809	
Sum N. 24,645	
,, S. 15,267	
Difference 9,378 which is the whole northward movement, in miles.	

Eastward forces.	Westward force.
1,172	1,578
1,205	
6,438	
3,426	
7,986	
11,959	
Sum E. 32,186	
,, W. 1,578	
Difference 30,608 which is the whole eastward movement, in miles.	

Hence the whole resultant movement is found, by a single triangle, either drawn or calculated, to be towards E. 17° 2′ N., and its extent 32,012 miles, or equivalent to a

constant wind during the whole year from 17° south of west, at the rate of $3\frac{3}{8}$ miles an hour.

For further information on this subject, we must refer to other works, and especially to Sir W. Snow Harris's report to the British Association in 1844, on the working of Whewell's and Osler's anemometers at Plymouth in the years 1841, 1842, and 1843. In the Association Report (vol. xx.) is a notice of the registers for Mr. Osler's new integrating anemometer. A sheet of plain paper, placed in the instrument under a registering-pencil, is moved forward by rotating hemispherical fans, at the rate of one inch for every two miles of air that passes: this same pencil, having a lateral motion given to it by a vane, records the point of the compass from which the wind blows; and a clock hammer descending every hour strikes its mark on the margin of the paper to express the time. Thus in a single line are given, 1st, the length of the current; 2ndly, the direction of the current; 3rdly, the time occupied in passing a given station marked hourly, or at any shorter interval that may be desired.

Note.—On the Air-Pump Gauge.*

The amount of rarefaction in the receiver of an air-pump is measured by the barometer gauge. This consists (A) of a column of mercury, pressed up through a long tube by the force of the external air, acting against the diminishing resistance (as shown in Fig. 7, p. 21), or (B) of an already existing mercurial column, similar to the barometer, which, being placed in connection with the receiver to be exhausted, will gradually fall as the air is withdrawn. In the *short barometer gauge* this column is only 10 or 12 inches high, so that it does not begin to act until the air in the receiver is exhausted to the point at which it will support that height of mercury.

1. To obtain the altitude of the column sustained by the air in the receiver, subtract the height of the gauge (A) from the height of a

* Abridged from an M.S. communication to the author, by Sir W. Snow Harris.

standard barometer at the time; or take the altitude of the column (B), as shown above the cistern.

2. To obtain the density, elasticity, or quantity of air left in the receiver, divide the height of the mercurial column in the gauge by the standard barometric altitude at the time.

3. To obtain the proportional quantity abstracted from the receiver, divide the gauge indication by the standard barometric altitude at th time.

4. To obtain the degree of exhaustion, or times of rarefaction, divide the standard barometric altitude by the column sustained by the receiver.

Gauge Indications, being Elevation of A or Descent of B.	Column sustained by the Air in the Receiver.	Elastic Force of Air in the Receiver.	Ratio of Indication of Gauge to the Standard Barometer at 30 ins., or quantity abstracted.	Ratio of Column sustained to the Barometric altitude at 30 inches, or Quantity in Receiver.	Degree of Exhaustion or Rarefaction.
Inches.	Inches.	lbs.			Times.
0	30	15	0	$1 = \frac{30}{30}$	0
1	29	14·5	$\frac{1}{30}$	$\frac{29}{30}$	$\frac{30}{29} = 1·04$
2	28	14	$\frac{2}{30} = \frac{1}{15}$	$\frac{28}{30} = \frac{14}{15}$	$\frac{30}{28} = 1·07$
5	25	12·5	$\frac{5}{30} = \frac{1}{6}$	$\frac{25}{30} = \frac{5}{6}$	$\frac{30}{25} = 1·2$
10	20	10	$\frac{10}{30} = \frac{1}{3}$	$\frac{20}{30} = \frac{2}{3}$	$\frac{30}{20} = 1·5$
15	15	7·5	$\frac{15}{30} = \frac{1}{2}$	$\frac{15}{30} = \frac{1}{2}$	$\frac{30}{15} = 2$
20	10	5	$\frac{20}{30} = \frac{2}{3}$	$\frac{10}{30} = \frac{1}{3}$	$\frac{30}{10} = 3$
25	5	2·5	$\frac{25}{30} = \frac{5}{6}$	$\frac{5}{30} = \frac{1}{6}$	$\frac{30}{5} = 6$
And so on up to the never attained limit,					
30	0	0	$\frac{30}{30} = 1$	$\frac{0}{30} = 0$	$\frac{30}{0} = \propto$

N.B.—If the barometer be more or less than 30 inches, substitute the quantity indicated for 30 and alter the fractions accordingly.

THE END.

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